COMPRESSIVE STRENGTH AND MICROSTRUCTURE PROPERTIES OF POLYMERIC CONCRETE INCORPORATING PULVERIZED FUEL ASH (PFA) AND MICROWAVE INCINERATED RICE HUSK ASH (MIRHA)

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by

SITI ASMAHANI BINTI SAAD

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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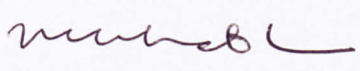
Approved by,



(AP Ir. Dr. Muhd Fadhil Bin Nuruddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SITI ASMAHANI BINTI SAAD

ABSTRACT

Polymeric concrete, the greener concrete attracts the attention of many parties in order to reduce the global warming problem caused by emission of CO_2 in Portland cement production. Annually, million tons of fly ash is generated causing disposal problem because they require proper landfilling process and is very costly. On the other hand, large amount of rice husk are produced annually in Malaysia. Rice husk is highly resistant to natural degradation that can threaten the environment. However, the rice husk ash contains high amount of silica that can increase the durability of concrete. Microwave incineration burning method is proven to be the best method used to produce amorphous silica content of rice husk ash. Hence, utilizing fly ash as major constituent and Microwave Incinerated Rice Husk Ash (MIRHA) in polymeric concrete can reduce the disposal problem as well as increasing the strength and durability of polymeric concrete.

This project focuses on determination of cement-free polymeric concrete capacity as an alternative to Ordinary Portland Cement concrete (OPC) for in-situ casting and the effect of utilizing waste material in polymeric concrete. Pulverized Fuel Ash (PFA) is used as the main constituent and MIRHA as replacement by 0%, 3%, 5% and 7%. Sodium hydroxide and sodium silicate solution are used as alkali activators of silica (Si) and aluminium (Al) in main binders while sugar is added to delay the setting time of the polymeric concrete. The polymeric concrete samples are exposed to three different curing regimes namely hot gunny sack curing, ambient temperature curing and external exposure curing. Compressive strength test is carried out in 3, 7, 28 and 56 days to identify the strength of the polymeric concrete. Scanning Electron Microscopy (SEM) analysis is done to ascertain the microstructure properties of the produced polymeric concrete. It is concluded that external curing regime is the optimum curing method for in-situ casting in polymeric concrete production. Compressive strength of polymeric concrete in external exposure curing method reaches up to 48.88 MPa at 28 days.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF STUDY

In recent research, inorganic polymer concrete or polymeric concrete has been introduced as a greener alternative to Portland cement concrete. The polymeric concrete can be made from various industrial waste materials such as pulverized fuel ash (PFA), ground granulated blast-furnace slag (GGBS) and contaminated soil. These materials are also referred to alkali activated cements. Large amount of aluminum and silica content in these waste materials partially dissolved in highly alkaline solution. These partially dissolved contents act as reagents for geopolymerization reactions to form desirable geopolymer concrete [1-2].

Pozzolanic cements depend on the presence of calcium. However, polymeric do not use the formation of calcium-silica-hydrates (CSH) for matrix formation and strength [3]. The difference in structural formation gives certain advantages to polymeric compared to ordinary Portland cement concrete [4].

Some of the main properties of polymeric concrete are: quick compressive strength development, low permeability, resistance to acid attack, good resistance to freeze-thaw cycles, and tendency to lower down the mobility of most heavy metal ions contained within the polymeric structures [5].

1.2 PROBLEM STATEMENT

The large demand for industrial and domestic energy produces million tons of fly ash generated each year by coal-fired power plant and need to be disposed via landfilling method. However, improper landfilling process of the waste product leads to soil and groundwater contamination. Hence, the better plan to manage the waste is always become the major concern. On the other hand, almost 2.2 million tons husks produced per year in Malaysia from agriculture waste contributing to 600 million tons of annual world husks production. Rice husk is highly resistant to natural degradation. Therefore, the utilization of rice husk as one of the pozzolanic material in concrete production is seen as a better option to handle the abundance of the agricultural waste.

Production of Portland cement is held responsible carbon dioxide (CO_2) emission. An article revealed that 1 tonne of CO_2 is emitted from a cement clinker production per ton of cement production. Hence, it contributes to one of the major greenhouse gases as CO_2 contributes 65% of global warming [7]. Since the global warming issue that causing climate change has become major discussion widely, several steps has been considered to reduce the usage of Portland cement in order to address this issue. In this regard, the geopolymer technology approach introduced by Davidovits (1988) [9] gives an alternative in recent concrete industry as well as to preserve the environment.

Currently, most of polymeric concrete researches are concentrating on precast concrete production. The curing methods used in this approach are steam curing and oven curing. Rangan et al. (2006) investigated the effect of curing temperature on compressive strength of polymeric concrete. It is proven that higher curing temperature resulted in higher compressive strength. However, in-situ casting of polymeric concrete is never been cited in any research. In this regard, this research will highlight on implementing in-situ casting to produce quality polymeric concrete.

1.3 OBJECTIVES

The objectives of this research are as follows:-

- To determine the capacity of cement-free polymeric concrete as an alternative to Ordinary Portland Cement (OPC) concrete.
- To establish the effect of waste materials namely pulverized fuel ash (PFA) and microwave incinerated rice husk ash (MIRHA) in polymeric concrete.
- To identify the suitable curing method for in-situ casting.
- To identify the compressive strength development of polymeric concrete incorporating pulverized fuel ash (PFA) and microwave incinerated rice husk ash (MIRHA) at 0%, 3%, 5% and 7%.
- To ascertain the microstructure properties of polymeric concrete using scanning electron microscopic (SEM).

1.4 SCOPE OF STUDY

This study encompasses the compressive strength development and microstructure properties of polymeric concrete incorporating PFA and MIRHA. The lists of the test in the laboratory specimen that will be conducted are:-

- Compressive test
- UPV test
- Rebound hammer test
- SEM analysis

In this study, the following parameters are considered in the mix proportions:-

- PFA content
- MIRHA content
- Coarse aggregate content
- Fine aggregate content

- Sodium hydroxide amount
- Sodium silicate amount
- Sugar amount
- Water amount

The testing cube size used is 100mm x 100mm x 100mm. The specimens will be demolded 24 hours after casting, cured for 2 days and tested at 3 days, 7 days and 28 days. The research will be focused on three different types of curing methods which are hot gunny sack curing, ambient temperature curing and External exposure curing. The specimens will be separated in three mixes which are 350 kg/m^3, 400kg/m^3 and 450kg/m^3 of PFA as well as incorporation of 0%, 3%, 5% and 7% MIRHA. For sodium hydroxide solution, the optimum concentration of the solution is 8.0 Molar. Meanwhile, for sodium silicate, the ratio of SiO_2:Na_2O is 2.0.

CHAPTER 2: LITERATURE REVIEW

2.1 CEMENT REPLACEMENT MATERIALS

The demand of concrete as a construction material increases every year causing the demand of Portland cement. It is estimated that the production of cement will increase from approximately 1.5 billion tons in 1995 to 2.2 billion tons in 2010 (Malhotra, 1999).

In these days, worldwide basic construction material increases, causing the increment of Portland cement demand. However, the production of Portland cement is held responsible carbon dioxide (CO_2) emission. An article revealed that the CO_2 emitted from the cement clinker production per ton of binder, including blending with ashes and slags estimated to be 0.815 ton [6]. Hence, it contributes to one of the major greenhouse gases as CO_2 contributes 65% of global warming [7]. Since the global warming issue that causing External change has become major discussion widely, several steps has been considered to reduce the usage of Portland cement in order to address this issue. The steps includes application of supplementary cementing material such as pulverized fly ash (PFA), ground granulated blast-furnace slag (GGBFS), rice husk ash (RHA) and as well as the research of alternative binders to Portland cement where polymeric concrete is introduced.

In this respect, the research of concrete with different cementitious materials or replacement material has been gaining much attention. Considering the world situation with respect to cement demand and External change due to global warming, cementitious material like ground granulated blast furnace slag (GGBFS), silica fume, pulverized fuel ash (PFA) and rice husk ash (RHA) can be utilized. The replacement material can be used in geopolymer technology, which promises reduction of global warming problem by low CO_2 emission. Figure 2.1 shows the total calculated CO_2

emission of geopolymer binders as a function of the dissolved solids (Na_2O + SiO_2) content of the activating solution which is principal emitting components [15].

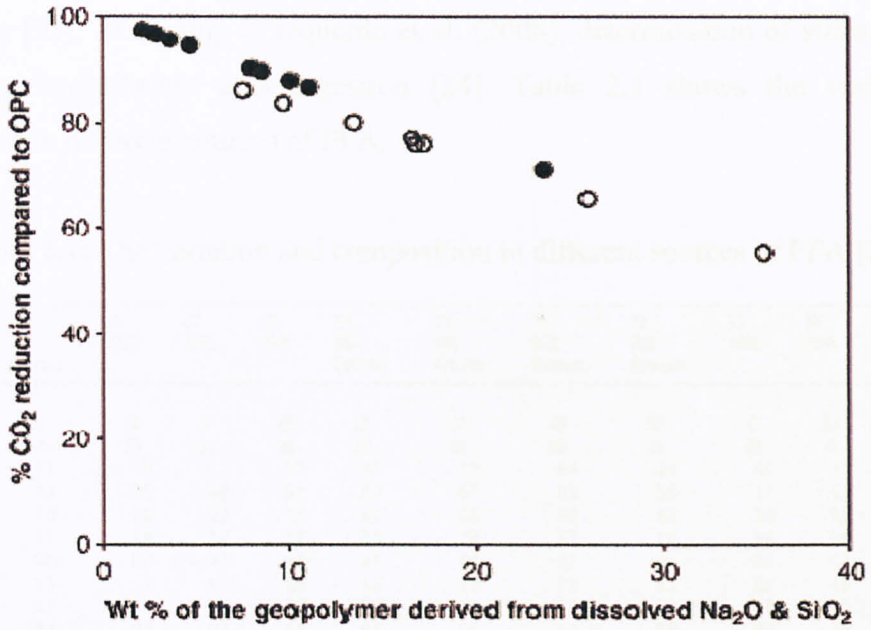


Figure 2.1: Total estimated CO_2 emission of geopolymer binders as a function of dissolved components content [15].

2.2 PULVERIZED FLY ASH (PFA)

Fly ash is a by-product generated by coal-fired power plants worldwide. Annually, million tons of the by-product produced in order to satisfy the demand for industrial and as domestic energy. Generally, fly ash is used mainly as additive or filling material in concrete mix. However, the usage of the material only about 20-30% of the total generated fly ash. The remaining of the unused material is disposed via landfilling technique [8]. Without a proper disposal of the by-product, it will lead to environmental pollution. One of the efforts to be more environmental friendly is to reduce the use of OPC by partially replacing the amount of cement in concrete with by-products materials such as fly ash. Hence, utilization of PFA in concrete production will reduce the problem caused by improper disposal of PFA.

The sources of PFA are mainly come from combustion of coal and co-fired fly ash obtained from the combustion of coal where the amount of coal as more than 75% with minor amounts of alternative fuels such as petroleum coke, sewage sludge and olive waste [23]. According to Izquerdo et al. (2008), determination of silica content is done using hydrofluoric acid digestion [24]. Table 2.1 shows the variation and composition in different sources of PFA.

Table 2.1: The variation and composition in different sources of PFA [24].

Sample, fuel blend, coal, others	I6 90% Biomass	A1 100%	C1 100%	C2 100%	C3 76% Petcoke	C4 96% Petcoke	T1 86% Biomass	T2 90% Biomass	T3 100%	T4 100%	T5 100%	Slag -
Composition (wt%)												
SiO_2	50	58	54	43	52	51	49	50	47	53	52	39
Al_2O_3	29	23	23	26	25	26	28	21	25	27	29	11
CaO	5.2	3.5	3.5	5.3	3.0	2.9	6.4	4.5	6.9	3.1	1.7	41
Na_2O	0.3	0.6	0.9	0.1	0.7	0.7	0.3	0.6	1.2	0.1	0.5	0.3
K_2O	1.4	1.6	3.2	1.2	3.6	3.6	0.8	4.3	1.9	0.5	2.3	0.4
MgO	1.2	1.8	2.0	1.2	1.8	1.8	1.7	1.9	3.8	0.6	1.0	7.0
MnO	0.04	0.1	0.1	0.04	0.1	0.1	0.1	0.1	0.1	0.1	0.03	0.3
TiO_2	1.4	1.1	1.0	0.9	1.0	1.0	1.8	0.5	0.9	1.8	1.5	0.5
SO_3	0.7	0.2	0.4	0.9	0.5	0.5	0.4	0.9	1.0	0.5	0.4	2.2
P_2O_5	2.2	0.5	0.8	0.5	0.6	0.5	1.1	0.8	0.7	1.6	0.2	<0.02
Fe_2O_3	5.8	6.1	8.5	19	7.0	6.9	4.3	8.0	9.3	7.4	8.3	0.3
Composition (mg/kg)												
As	38	24	73	133	91	98	66	45	48	55	109	2
B	239	217	66	396	81	100	396	328	297	255	97	27
Ba	2293	1287	1009	684	1324	1412	1811	1370	2037	2182	1757	680
Cd	3	3	4	2	2	2	4	6	2	2	1	0.5
Co	44	33	29	35	40	38	64	50	55	112	72	0.4
Cr	221	167	156	182	231	210	204	200	140	196	171	16
Cu	189	97	87	62	112	113	112	106	186	154	254	5
Li	244	153	166	283	238	241	186	149	167	79	268	76
Mo	12	17	11	15	27	14	15	17	13	7	14	<0.01
Ni	131	102	65	97	882	158	139	131	152	377	136	4
Pb	146	47	71	94	152	130	90	72	208	54	102	1
Rb	45	78	154	96	198	207	42	100	108	22	127	11
Sb	23	6	20	6	19	19	5	6	17	2	9	<0.01
Se	14	19	2	35	23	22	44	34	-	-	-	2
Sn	21	6	7	12	12	12	11	7	10	9	10	0.1
Sr	1258	1017	396	978	577	595	1717	1116	1189	988	1920	951
U	11	7	10	19	7	7	13	11	25	5	17	13
V	125	248	218	202	3894	401	286	231	325	226	323	20
Zn	392	136	110	217	193	185	121	177	200	153	143	47
Dosage (%)												
Fly ash	59	57	68	68	70	68	59	59	63	63	61	-
Slag	18	17	13	13	12	12	18	18	16	16	17	-
Water	12	14	11	11	11	11	12	12	11	11	11	-
K-Sil	12	11	9	8	8	8	12	12	11	11	11	-

There are two types of fly ash generated by power plants which are known as low calcium fly ash (LFA) and high calcium fly ash (HFA). LFA is in accordance with

ASTM Class F while HFA is in accordance with ASTM Class C. The chemical composition and physical properties of LFA and HFA is illustrated in Table 2.2.

Table 2.2: Chemical composition (% of total mass) and physical properties of low calcium fly ash (LFA) and high calcium fly ash (HFA) [16].

Components	LFA	HFA
SiO_2	57.8	38.1
Al_2O_3	23.0	20.7
Fe_2O_3	3.5	5.2
CaO	9.9	23.9
MgO	1.5	4.6
SO_3	0.3	1.9
Na_2O	2.3	1.4
K_2O	0.5	0.4
Loss on Ignition	0.5	0.4
Glass Content	83.9	64.0
Quartz	4.1	9.0
Mullite	10.2	7.5
Hematite	1.4	0
Density (g/cm^3)	2.0	2.6
Fineness (cm^2/g)	2800	3630
% Passing 45μm	74	85

Based on X-ray diffraction analysis, C.Shi et al. (1995), concludes that LFA produces amorphous constituent compare to HFA which contain quartz in the hydration product. Figure 2.2 shows the result of the X-ray diffraction.

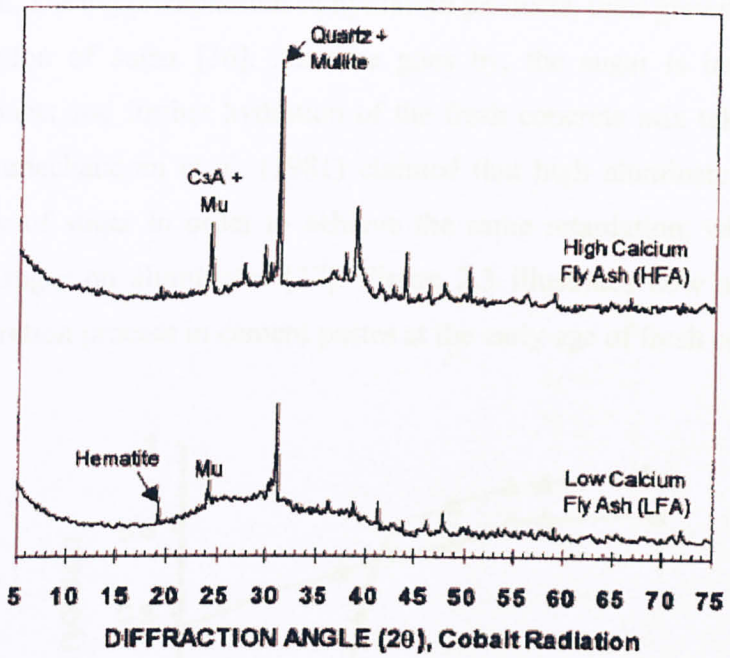


Figure 2.2: X-ray Diffraction for high calcium fly ash (HFA) and low calcium fly ash (LFA) [16].

2.3 SUGAR ADDITION IN CONCRETE PRODUCTION

In concrete production, sugar is well known as a cement retarder and has been used in cementing operations to delay setting time of the fresh concrete mix state. However, experts disagree about the effect that sugar has on fresh concrete mix, some believe that it acts as both an accelerator and a retarder depending on the concentration, but the majority believe that the sugar acts as a retarder only.

As mention before, sugar has long been known to delay hydration and setting time. This phenomenon was noticed by accident when it was observed that cement stored in old sugar sacks failed to set properly [35]. According to Young (1972), at first stage, sugar bonds to the aluminate phases by complexing or chelating, where it forms a ring by combining aluminate and hydrogen bonds from sugar. Dissolution of ions from the hydrating calcium-silicate phases then formed and causing a higher concentration of

ions in solution. During precipitation of hydration products, their growth is slowed down by the adsorption of sugar [36]. As time goes by, the sugar is integrated into the hydration products and further hydration of the fresh concrete mix takes place. On the other hand, Ramachandran et al. (1981) claimed that high aluminate cement needs a higher quantity of sugar in order to achieve the same retardation, where it relates to adsorption of sugar on aluminates [37]. Figure 2.3 illustrates how addition of sugar retards the hydration process in cement pastes at the early age of fresh cement paste.

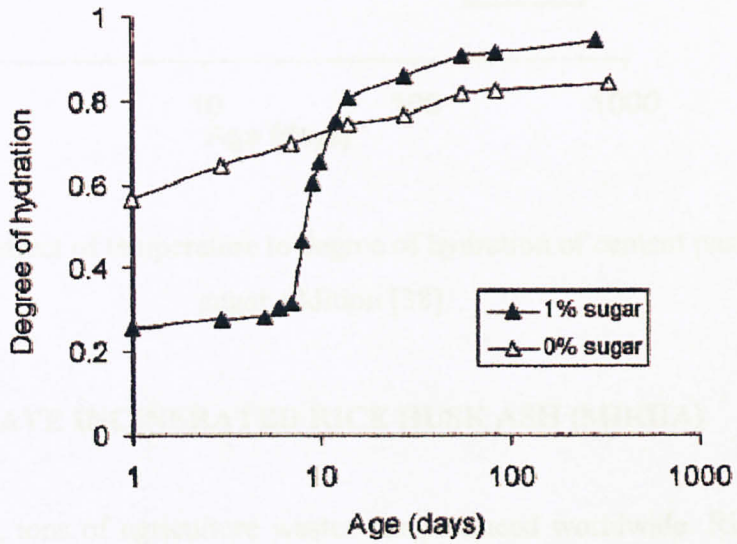


Figure 2.3: Effect of 1% sugar delays to the hydration process of cement pastes [38].

Despite of delay the setting time, addition of sugar also increases the degree of hydration provided the curing temperature is increased [38]. This is supported by experiments done by M.C.G. Juenger and H. M. Jennings (2001). Based on their experimental works, 1% sugar addition to cement paste retards hydration time for more than three months at 20°C curing temperature. However, at 40°C curing temperature, the retardation time is greatly reduced. Figure 2.4 showed the degree of hydration versus age in days graph at various curing temperature plot. From the plotted graph, it can be clearly seen that increment of curing temperature will boost up the degree of hydration of cement paste.

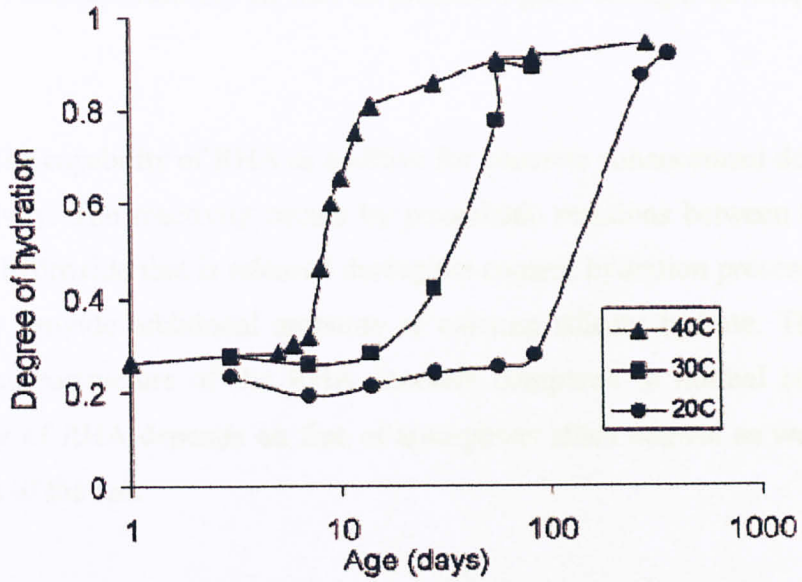


Figure 2.4: The effect of temperature to degree of hydration of cement paste with 1% sugar addition [38].

2.4 MICROWAVE INCINERATED RICE HUSK ASH (MIRHA)

Every year, tons of agriculture wastes are produced worldwide. Rice husk, the by-product of paddy is one of the agriculture wastes generated. In Malaysia, Almost 2.2 million tons husks produced per year from agriculture activity, contributing to 600 million tons of annual world husks production. Disposal of the by-product is very difficult because it has rough and abrasive surface that highly resistant to natural degradation.

Despite of the difficulity to dispose the waste, rice husk ash (RHA) that obtained from burning rice husk is revealed to be pozzolanic material that has substantial amount of silica. The burned rice husk contains about 20% by weight of the husk that recovered as ash in which more than 75% by weight of the rice husk ash is silica. Unlike natural pozzolanic material, the ash is an annually renewable source of silica. Thus, it is proved that the use of RHA in concrete leads to workability improvement, reduction of heat

evolution and permeability as well as promotes good strength development of concrete [27-31].

The capability of RHA as additive for concrete enhancement depends on its level of reactivity. The reactivity occurs by pozzolanic reactions between the silica and the calcium hydroxide that is released during the cement hydration process. These reactions basically provide additional amounts of calcium silicate hydrate. Thus, it leads to a denser microstructure of the RHA concrete compared to normal concrete [32]. The reactivity of RHA depends on fine or amorphous silica content as well as the porosity structure of the ash.

The addition of Rice Husk Ash (RHA) in concrete was patented in 1924 [33]. Until 1978, all the studies were concentrated of using ash produced from uncontrolled combustion. Based on studies done by P.K Mehta, it is concluded that burning rice husk under controlled temperature and time conditions produces ash containing silica in amorphous form [32]. Besides, uncontrolled burning condition to produce RHA may have carbon that is not completely burnt. Figure 2.5 shows the typical schematic shape of RHA furnace.

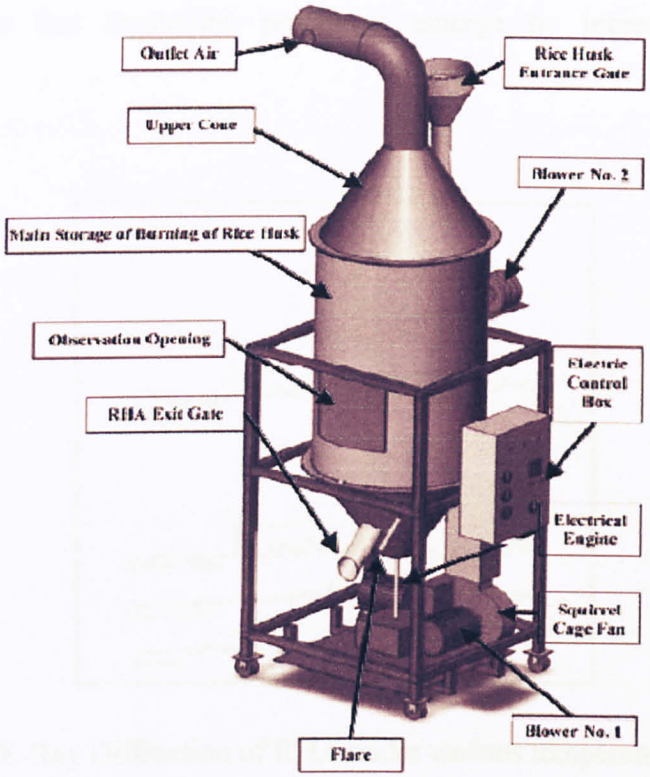


Figure 2.5: The typical schematic shape of rice husk ash furnace [32].

In concrete production, the presence of amorphous silica can enhance the quality of concrete by the formation of calcium silicate hydrate (C-S-H) gels [17]. Recent research shows that pozzolanic activity varies with different burning method used. Based on the research, RHA produced by furnace burning has the highest value of pozzolanicity [17]. Selection of a proper burning method is very crucial in order to produce RHA with high reactive silica content. Hence, microwave incinerator is seen as one of the suitable option to produce amorphous RHA with high content of SiO_2 where it assists in enhancing the concrete properties.

Realizing the fact that microwave incinerator can be utilized to produce amorphous RHA, microwave incinerated rice husk ash (MIRHA) is introduced as another cement replacement material in concrete technology. Based on research, rice husk that has been incinerated at 800°C will give the most amorphous constituent [18].

Figure 2.6 shows that crystalline properties emerge by increasing the burning temperature.

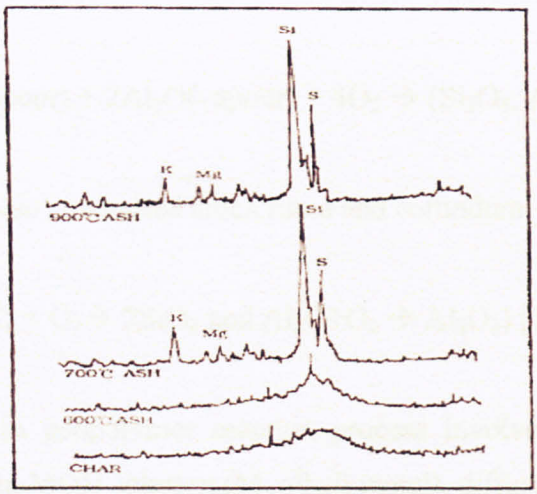


Figure 2.6: The X-Ray Diffraction of RHA under various temperature burning [18].

2.5 GEOPOLYMER

Enthusiastic researchers keep finding the new material that durable and have high economic value. In 1978, Davidovits introduced geopolymeric binders that could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium. Then these binders are termed as geopolymers.

2.5.1 Geopolymer Reaction Process

In order to produce geopolymer binders, alkaline liquid is used to react with silicon (Si) and aluminium (Al), taken from sources in by-product material such as fly ash and RHA. Chemical reaction of alumino-silicate oxides with alkalis and alkali–polysilicates yielding polymeric Si–O–Al bonds with a $(Si_2O_5, Al_2O_2)_n$ formula. This is accomplished by calcining alumino-silicate hydroxides
$(Si_2O_5, Al_2(OH)_4)$ through the reaction:

$$2(Si_2O_5, Al_2(OH)_4) \rightarrow 2(Si_2O_5, Al_2O_2)_n + 4H_2O$$

On the other hand, the reaction could also be as condensation of SiO and Al_2O vapours according to reaction:

$$4SiO(vapour) + 2Al_2O(vapour) + 4O_2 \rightarrow (Si_2O_5, Al_2O_2)_n$$

This reaction produces also condensed silica fume and corundum:

$$(2SiO + O_2 \rightarrow 2SiO_2 \text{ and } Al_2O + O_2 \rightarrow Al_2O_3)$$ [11].

The basic step in geopolymer reaction process involves dissolution of solid alumino-silicate oxides in MOH solution (M: alkali metal), diffusion or transportation of dissolved Al and Si complexes from the particle surface to the inter-particle space, formation of a gel phase resulting from the polymerization between added silicate solution and Al and Si complexes and finally hardening of the gel phase [3].

2.5.2 Geopolymer Chemical Structure

The types of polysialates distinguished are illustrated in Figure 2.7 [11]. The complex geopolymer structure consists of chains, sheet like and three dimensional networks made up of various Q unit types of connected SiO_4 and AlO_4 tetrahedra [12].

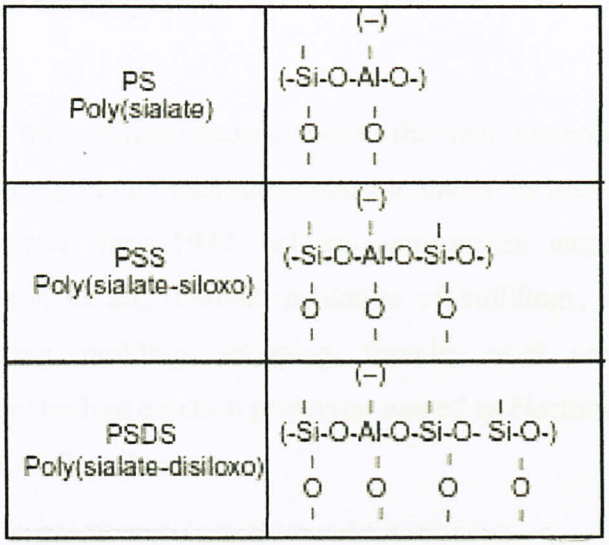


Figure 2.7: Types of polysialates [11].

Polysialates are chain and ring polymers with Si^{4+} and Al^{3+} in four-fold coordination with oxygen (See Figure 2.8). The components range from amorphous to semi-crystalline. The amorphous to semi-crystalline three dimensional silico-aluminatestructures are named as geopolymers [11].

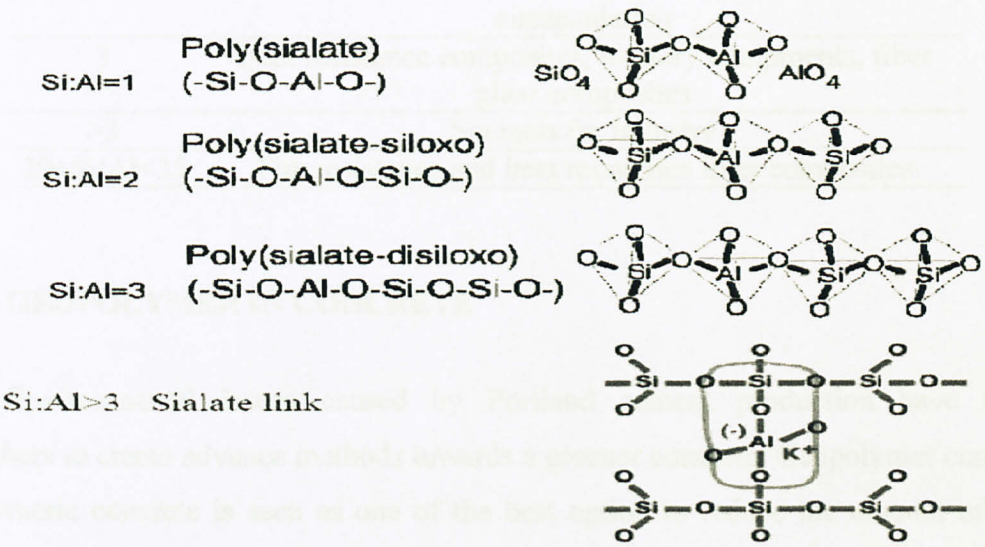


Figure 2.8: Chemical structures of polysialates [11].

2.5.3 Application of Geopolymer

Various fields have utilized geopolymer as the main material for construction. In other word, geopolymer gives a tremendous boost to creativity and innovation. The field of application developed since 1979 includes aeronautical engineering, the nuclear sector, the reproduction of art, thermal insulation of buildings, furnace insulation in mechanical engineering, molding, stamping, foundry work and metal casting. In addition, a geopolymer tooling aviation prototype named as Northtrop Aviation has been designed for new US Airforce bomber.

On the other hand, Davidovits (1999) proposed the possible applications of the geopolymers depending on the molar ratio of Si to Al. The details are shown in Table 2.3 as given follows.

Table 2.3: Application of geopolymer based on Si/Al molar ratio [19].

Si/Al	Application
1	Bricks, ceramics, fire protection
2	Low CO2 cements, concrete, radioactive and toxic waste encapsulation
3	Heat resistance composites, foundry equipments, fiber glass composites
>3	Sealants for industry
20<Si/Al<35	Fire resistance and heat resistance fiber composites

2.6 GEOPOLYMER IN CONCRETE

Environmental issues caused by Portland cement production have made researchers to create advance methods towards a greener concrete. Geopolymer concrete or polymeric concrete is seen as one of the best option to reduce the amount of CO_2 emitted in Portland cement production in order to satisfy the construction material needs. Generally, polymeric concrete is produced by alkali activation process in cement.

2.6.1 Concrete Polymerization

Basically, the geopolymer, as introduced by Davidovits in 1972, the tri-dimensional alumino-silicates that are formed at low-temperature and short time by naturally occurring alumino-silicates [9]. In these days, a lot of names describing those materials introduced including alkali-bounded-ceramics, hydroceramics and alkali-activated-cement. Hence, creates a lot of confusion. In order to make it simple, in all cases alkali-activation is a basic concept in polymeric concrete mix [10].

The chain of sialate (silicon-oxo-aluminate) consists of SiO_4 and AlO_4 tetrahedra linked alternately by sharing all oxygen atoms. Positive ions that refers to Na^+, K^+ and Ca^{2+}, must be there in the chain to balance the negative charge of Al^{3+}. Poly(sialates) are chain and ring polymers with Si^{4+} and Al^{3+} in 4-fold coordination with oxygen. Given that the empirical formula is as follows:

$$M_n(-SiO_2)_z\text{-}AlO_2)_n.wH_2O$$

Where z is 1, 2 or 3, M is a monovalent cation such as K^+ or Na^+ and n is the degree of polycondensation.

On the other hand, based on the schematic formation as illustrated in Equation (1) and (2) [13], it can be seen in Equation (2) that water is dispersed out during the chemical reaction that happens in the polymeric chain formation.

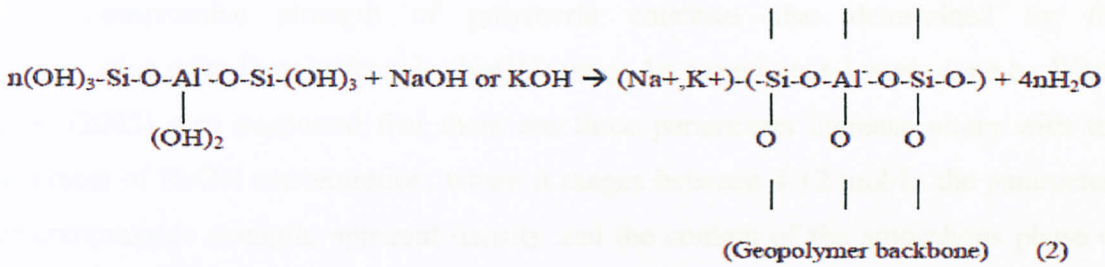
$$n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH \text{ or } KOH \rightarrow Na^+,K^+ + n(OH)_3\text{-Si-O-Al}^-\text{-O-Si-}(OH)_3$$

(Si-Al materials)

$(OH)_2$

(Geopolymer precursor)

(1)



This activity occur in curing and further drying period, leaves discontinuous very tiny pores in the matrix. Therefore, provide benefits to the performance in the polymeric concrete development. Furthermore, the water only provides workability to the mixture in fresh state and does not influence the chemical reaction in polymeric chain formation. Unlike Portland cement concrete, chemical reaction of water occur in hydration process.

2.6.2 Properties of Polymeric Concrete

The physical performance of polymeric concrete has become a promising technology that offers valuable properties for commercial applications recently. For an example, fast hardening, high and early compressive strength. Furthermore, polymeric concrete provides better microstructure properties compared to Ordinary Portland Cement concrete (OPC).

2.6.2.1 Compressive Strength of Polymeric Concrete

Generally, compressive strength of polymeric concrete depends on several factors which are gel phase strength, adequate ratio of the gel phase or dissolute Al–Si particles, the distribution of the dissolute Al–Si particle sizes, the degree of crystallinity produced or amorphous and also the surface reaction between the gel phase and the dissolute Al–Si particles [5].

Laboratory test done by Davidovits (1999) shows that polymeric concrete can rapidly harden at room temperature and gain compressive strength in range of 20 MPa after 4 hours at 20°C and around 70-100MPa after 28 days. In other laboratory test conducted on polymeric mortars by Comrie et. al. (1988) reported that most of the 28-day strength was gained during the first 2 days of curing.

Compressive strength of polymeric concrete also determined by the concentration of sodium hydroxide (NaOH) used. An experimental work done by Wang et al. (2005) also supported that there are three parameters increase along with the increment of NaOH concentration, where it ranges between 4-12 mol/L. the parameters are compressive strength, apparent density and the content of the amorphous phase of metakaolinite-based polymeric concrete. This can be attributed to the enhanced dissolution of the metakaolinite particulates and hence the accelerated condensation of the monomer in the presence of higher NaOH concentration [34].

On the other hand, based on the laboratory done by Alvarez-Ayuso et al. (2007), the compressive strength shown by the polymeric concrete synthesized using 12M of NaOH is the highest for all the fly ashes subjected to the study. Only one type of fly ash shows that the optimum NaOH concentration is 8M [8]. Figure 2.9 shows the effect of NaOH concentration to the compressive strength of fly ash based polymeric concrete.

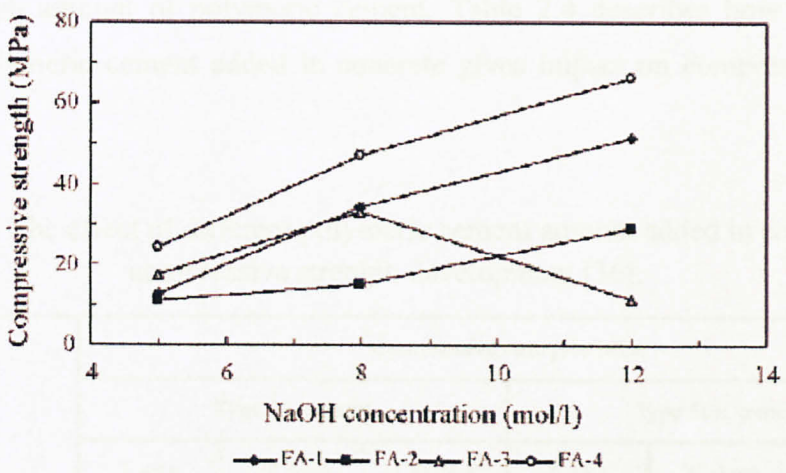


Figure 2.9: Compressive strength development of different fly ash samples subjected to various NaOH concentrations used [8].

According to a study done by E. Hewayde et. al. (2006), it is revealed that the increment of compressive strength at various ages is proportional to the dosage of polymeric cement added to ordinary Portland cement concrete mix. This property is due to the effect of the polymeric cement on the physical as well as the chemical characteristics of the hardened concrete. Physical effects include a significant reduction in the volume of large voids, which are leads to denser and homogenous mixture of hardened polymeric concrete [36].

On the other hand, formation of new hydration products in chemical effect can be seen, which offers a great contribution to compressive strength. Another contribution towards chemical effect is the transformation of calcium hydroxide into more stable hydration products such as CSH. However, there is limitation on the compressive strength development of polymeric concrete. The compressive strength decreased with respect to polymeric cement addition at certain amount of addition [36]. The reason behind this as may be due to the fact that the hydration process of polymeric concrete is delayed at high amount of polymeric cement. Table 2.4 describes how the different amount of polymeric cement added in concrete gives impact on compressive strength development.

Table 2.4: The effect of different polymeric cement amount added in concrete on compressive strength development [36].

Mixture	Compressive strength: MPa					
	Type 10 cement			Type 50E cement		
	7 days	28 days	120 days	7 days	28 days	120 days
Control mixtures	39·0	44·3	49·2	40·2	57·5	61·6
30% geopolymer	52·0	58·4	62·5	45·8	58·5	62·2
35% geopolymer	54·3	60·9	67·4	53·2	60·3	64·9
40% geopolymer	55·9	62·4	70·1	45·8	49·8	55·1
45% geopolymer	57·7	64·9	72·1	46·0	50·7	56·8
50% geopolymer	58·2	65·9	72·3	40·2	57·5	61·6

2.6.2.2 Microstructure Properties of Polymeric Concrete

The microstructure properties of polymeric concrete is said to be better compared to Ordinary Portland Cement (OPC) concrete. Based on a microstructure test using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) done by E. Hewayde et. al. (2006), it is revealed that the microstructure of the polymeric cement added concrete appears to be finer and denser than OPC concrete [14].

In Figure 2.10, the SEM micrograph shows the presence of calcium hydroxide (indicated by large white plates) as well as non-reactant lime particles. On the other hand, in EDX result, the elemental analysis indicates presence of calcium hydroxide and lime in the hydration products of the control concrete is abundant. Whereas in Figure 2.11, the elemental analysis of EDX result of the 40% added polymeric cement shows significant increase in peaks of calcium, silicon, magnesium and also potassium [14]. Hence, this factor gives contribution to denser and homogeneous properties inside the polymeric concrete.

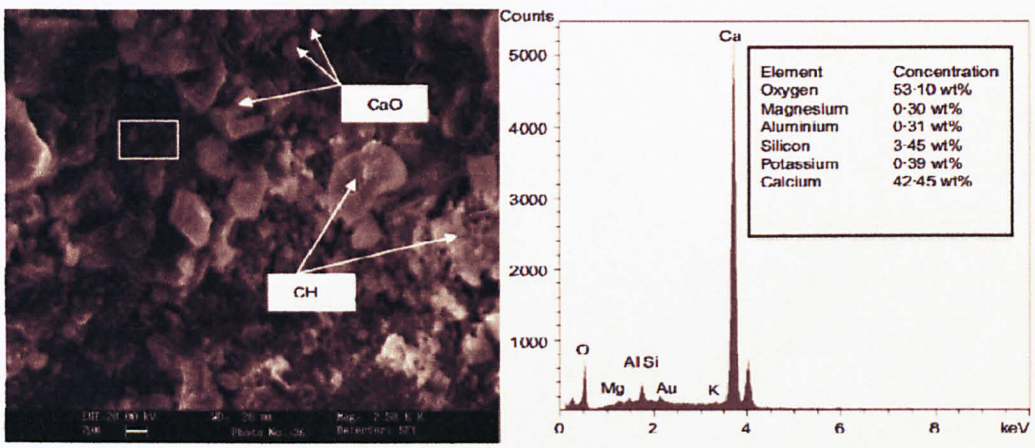


Figure 2.10: The SEM micrograph and EDX elemental analysis of control concrete [14].

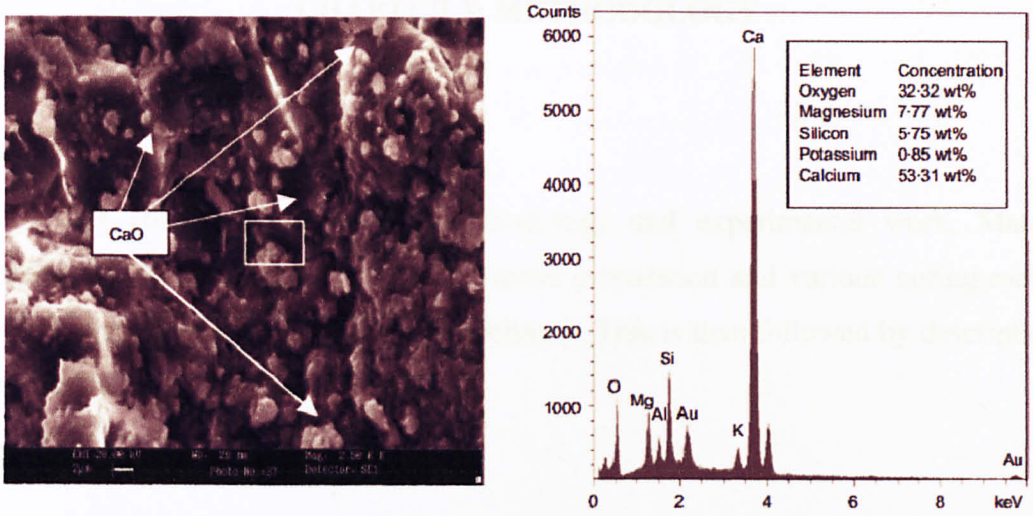


Figure 2.11: The SEM micrograph and EDX elemental analysis of 40% added geopolymer [14].

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methodology and experimental work. Materials selection, mixture proportions, test specimens preparation and various curing methods for the test specimens are explained accordingly. This is then followed by description of specimens test and procedures.

3.2 MATERIAL SELECTION

In this project, materials are selected in accordance to the specification to meet the objectives of project and comply with the appropriate British Standard (BS). The non standardized material is obtained with designed procedure and specific process for data gathering purposes in the project.

3.2.1 Pulverized Fuel Ash

In this project, PFA that will be used is taken from Manjung Power Station, Perak. According to American Standard Testing and Material standard (ASTM), the PFA taken is Class F PFA. It is known that PFA of Class F has low calcium content. The presence of high calcium content may interfere with the polymerization process of the polymeric concrete [20]. Hence, PFA of Class F is preferable in order to produce polymeric concrete in this project.

3.2.2 Microwave Incinerated Rice Husks Ash

Rice husks for this project are dried under direct sunlight to reduce moisture content hence less production of smoke when they are burnt. Dried rice husks then being burnt in automatic microwave incinerator up to 400°C to produce amorphous microwave incinerated rice husks ash (MIRHA) in one phase burning. Figure 3.1 shows the microwave incinerator used to produce MIRHA.

MIRHA is then ground in the ball mill using LA machine for 3000 times to increase its fineness. As cement replacement material (CRM), MIRHA should contain fine particle size in accordance to function as micro structure filler.

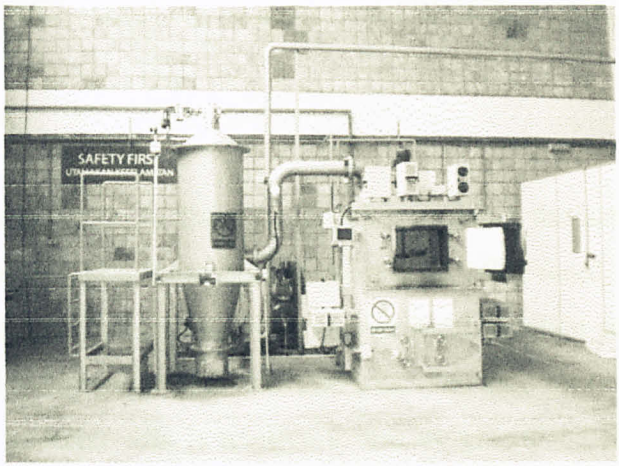


Figure 3.1: Microwave incinerator used to produce MIRHA.

3.2.3 Aggregate

In this project, coarse aggregate type used is crushed aggregate with maximum size of 20mm according to BS 812-103.2 1989 [21]. Furthermore, the coarse aggregates are prepared as Saturated Surface Dry (SSD) by washing the aggregates prior to mixing process. The reason of using SSD aggregate is to avoid the aggregate from absorbing water in the polymeric concrete mix. For fine aggregate, natural sand with maximum size of 5mm will be use to produce polymeric concrete.

3.2.4 Alkaline Solution

In order to produce alkaline solution, sodium silicate solution and sodium hydroxide (NaOH) will be combined. The sodium silicate solution is commercially available in various grades. In this project, the sodium silicate solution of grade A53 with SiO_2 to Na_2O ratio by mass value of 2.0 is used. Table 3.1 describes precisely on the percentage by mass of the sodium silicate solution that will be utilized in the project.

Table 3.1: The value of percentage by mass of components in sodium silicate solution.

Components	Percentage by mass
Na_2O	14.73%
SiO_2	29.75%
H_2O (water)	55.52%

3.2.5 Glucose Solution

Glucose solution is added to the mix in order to delay the setting time of the polymeric concrete in fresh state prior to casting process. In other word, glucose solution is act as a retarder to the mix. For glucose solution preparation, plain sugar is diluted in water and will be added to the polymeric concrete mix. The amount of sugar and water added to the polymeric concrete mix is relative to the weight of the PFA needed. The amount of sugar added in each mix is 3% while the amount of water used to dilute the sugar is 10%. Table 3.2 shows the amount of sugar and water relative to PFA weight.

Table 3.2: The amount of sugar and water relative to PFA weight.

Amount of PFA	Amount of sugar (3%)	Amount of water (10%)
350 kg/m^3	14 kg/m^3	35 kg/m^3

3.3 MIXTURE PROPORTIONS

Polymeric concrete is a new research done in the university. The correct proportion of the mix needs to be determined. Therefore, trial mix is conducted to obtain the data. In the actual mix, sugar has been used to as a retarder since the trial mix tends to set fast. Table 3.3 shows the content of every component in actual mix.

Table 3.3: The content of every component in the actual mix.

Type	Origin (kg/m^3)	Amount of Water			Reactive Material Content		
Fly Ash	350	0%	0	kg/m^3	51%	178.5	kg/m^3
NaOH	41	70.60%	28.95	kg/m^3	29.40%	12.05	kg/m^3
NaSiO2	103	55.52%	57.19	kg/m^3	44.48%	45.81	kg/m^3
Extra Water	35	100%	35	kg/m^3	0%	0	kg/m^3
TOTAL			121.14	kg/m^3	**TOTAL**	236.36	kg/m^3
Water/Binder Ratio			0.5				

Polymeric concrete mixtures will be mixed in three different batches with various amount of PFA. MIRHA is used to replace PFA content by 3%, 5% and 7% of PFA weight in the mixture proportion. Polymeric concrete specimens without addition of MIRHA are used as control. Table 3.4 describes the mix proportion that will be applied in this project.

Table 3.4: Mix proportion for sample preparation.

Code	Fly Ash Content (kg/m^3)	MIRHA (%)	MIRHA (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	NaOH solution (kg/m^3)	$NaSiO_2$ solution (kg/m^3)	Extra water (kg/m^3)	Sugar (kg/m^3)
A1	350	0	0	1200	645	41	103	35	10.5
A2	339.5	3	10.5	1200	645	41	103	35	10.5
A3	332.5	5	17.5	1200	645	41	103	35	10.5
A4	325.5	7	24.5	1200	645	41	103	35	10.5
B1	350	0	0	1200	645	41	103	35	10.5
B2	339.5	3	10.5	1200	645	41	103	35	10.5
B3	332.5	5	17.5	1200	645	41	103	35	10.5
B4	325.5	7	24.5	1200	645	41	103	35	10.5
C1	350	0	0	1200	645	41	103	35	10.5
C2	339.5	3	10.5	1200	645	41	103	35	10.5
C3	332.5	5	17.5	1200	645	41	103	35	10.5
C4	325.5	7	24.5	1200	645	41	103	35	10.5

3.4 PROCESS FLOWCHART OF SAMPLES PREPARATION

Process flowchart below summarized the main activities involved in sample preparation for data acquiring in this project.

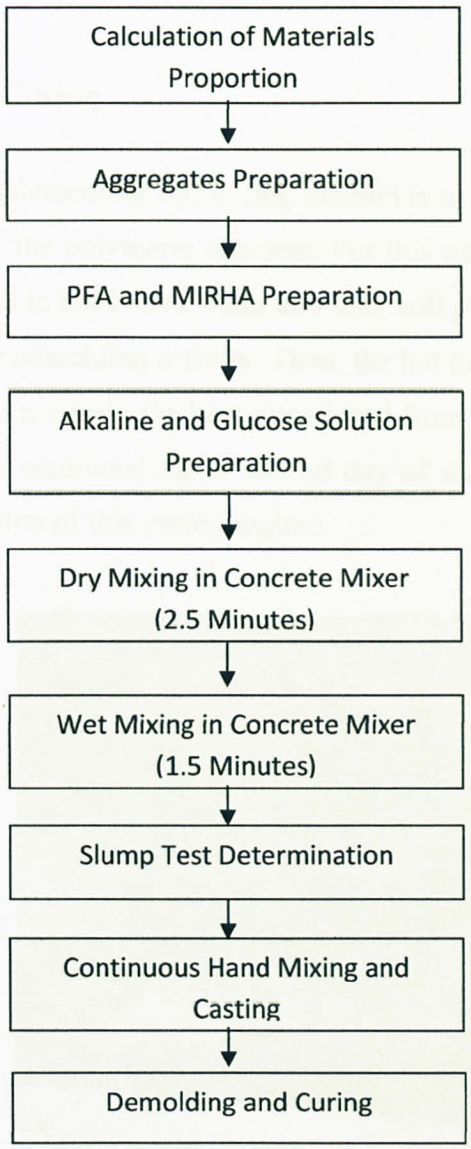


Figure 3.2: Process flowchart of sample preparation.

3.5 CURING METHOD

Curing is the one of the crucial part in concrete hardening process. In order to identify the best method of in-situ polymeric concrete casting, three different curing methods are applied in this project.

3.5.1 Hot Gunny Sack Curing

The purpose of implementing this curing method is to provide heat to accelerate polymerization process of the polymeric concrete. For this particular method, adequate gunny sacks will be soaked in hot boiled water and they will placed on top of the harden geopolymer concrete after demolding activity. Then, the hot gunny sack will be covered using clear plastic sheet to maintain the heat transferred from the hot gunny sack to the samples longer. Curing is continued up to second day of curing duration. Figure 3.3 illustrates the implementation of this curing regime.

Figure 3.3: Hot gunny curing method.

3.5.2 Ambient Temperature Curing

In this method of curing, heat needed to assist polymerization process is provided by the environment temperature. For this method, the samples are placed outside concrete laboratory under shelter to avoid direct sunlight and rain exposure. Figure 3.4 illustrates the implementation of this curing regime.

Figure 3.4: Ambient temperature curing method.

3.5.3 External Exposure Curing

External exposure curing method is the curing process that will utilize the heat from surrounding area. A chamber covered with transparent plastic sheet is used to allow UV penetration and thus heat up the chamber. The chamber also protects the early age of polymeric concrete from direct exposure to environmental moisture i.e. rain. Heat is needed to boost the polymerization process namely polycondensation reaction in polymeric concrete production. The temperature inside the chamber is ranging between 25°C to 55°C. Figure 3.5 illustrates the implementation of this type of curing regime.

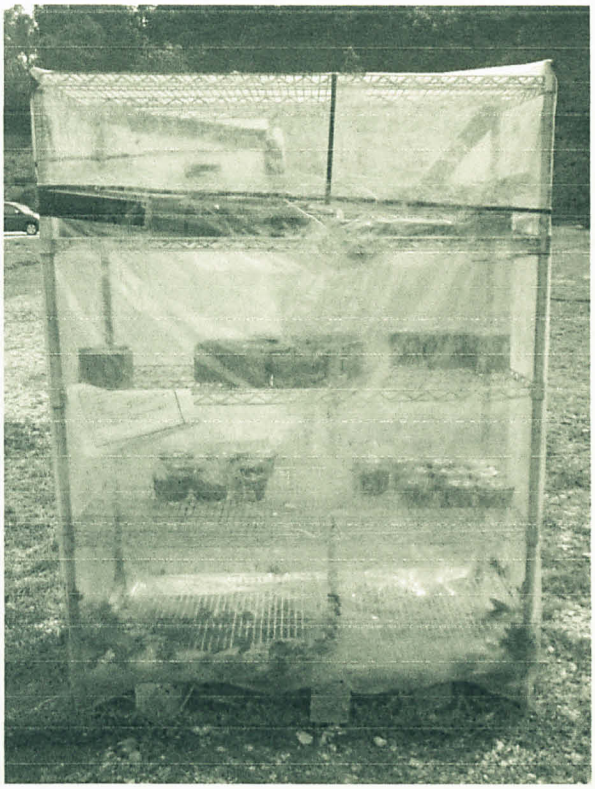


Figure 3.5: External exposure curing method.

3.6 POLYMERIC CONCRETE TESTING AND ANALYSIS

Testing of polymeric concrete samples is conducted for both fresh and hardened concrete. Workability characteristic is analyzed using slump test. Besides, testing on hardened polymeric concrete is divided into two categories which are destructive test and non-destructive test. Table 3.5 shows the experimental details of polymeric concrete testing method that will be used in this project.

The destructive test that will be conducted is only compressive strength test. While non destructive tests comprises of ultrasonic pulse velocity (UPV), rebound hammer test, X-Ray Fluorescent analysis (XRF) and Scanning electron Microscopy (SEM) also will be conducted to complete the project.

3.6.1 Slump Test

In this project, slump test will be conducted according to BS EN 12350-2:2000. Steel cone mould with 305mm high and smaller opening at the top is used. polymeric concrete sample will be filled in the cone mould in three layers with 25 times tamping on each layer using standard 16mm diameter steel rod. After the last layer, the top surface was struck off by means of a shredding and rolling motion of the tamping rod. The cone slowly lifted and the height of collapse slump is directly measured to the nearest 5mm to the top surface of the cone [22].

3.6.2 Compressive Strength Test

Compressive strength test is done to measure the strength development of the polymeric concrete. The test will be conducted according to BS EN 12390-3:2002 using Digital Compressive Testing Machine. Non destructive tests will be conducted prior to compressive strength test. The measurement is taken for three cube samples at concrete ages of 3, 7 and 28 days.

3.6.3 Ultrasonic Pulse Velocity Test

Ultrasonic Pulse Velocity (UPV) Test is conducted to analyze the integrity of polymeric concrete sample. Direct transmission method where an electro acoustical transducer that is placed on the opposite surface of longitudinal pulse receiver is done according to BS EN 12504-4:2004. UPV test will be conducted using Portable Ultrasonic Non Destructive Digital Indicative Tester (PUNDIT) at concrete ages of 3, 7 and 28 days.

3.6.4 Scanning Electron Microscropy Analysis

Scanning Electron Microscopy (SEM) analysis is carried out to describe the inner microstructure condition of the produced polymeric concrete at various percentage of MIRHA replacement. The analysis will be performed using LEO 1430 VP Inca X-

Sight Oxford instrument. However, to calibrate the analysis using the equipment, the sample needs to be conductive in order to obtain full observation. SEM equipment must be operated at a suitable pressure to assist the operation of the equipment.

Table 3.5: Experimental details for polymeric concrete sample.

Concrete Type	Test Type	Standard	Equipment	Testing Age	Sample Size	Number of Test	Measurement Unit	Curing
Fresh Concrete	Slump Test	BS EN 12350-2:2000	Slump Cone	Fresh Concrete	-	Each batch	mm	Harden cubes will be cured under three different curing regimes
Hardened Concrete (Non-Destructive Test)	Ultrasonic Pulse Velocity (UPV)	BS EN 12504-4:2004	PUNDIT UPV Tester	3, 7 and 28 days	3 Surfaces $100mm^3$ cube	6 readings	km/s	
Hardened Concrete (Destructive Test)	Compression Strength	BS EN 12390-3:2002	Compression Testing Machine	3, 7 and 28 days	$100mm^3$ cube	3 cubes/ concrete age	N/mm^2	
Scanning Electron Microscopy Analysis	Microstructure Analysis	-	LEO1430 VP Inca X-Sight Oxforf Instrument	3, 7 and 28 days	$100mm^3$ cube	1 cube/ concrete age	-	

CHAPTER 4: RESULT AND DISCUSSION

4.1 WORKABILITY

Workability, also known as the degree of easiness to work with the concrete of fresh state concrete was determined using slump test. The slump test was done in every mix of polymeric concrete. The mixes were separated according to different percentage of MIRHA incorporation in the polymeric constituent. Apart from that, every cube was coded according to respective curing regime. Table 4.1 illustrates the average slump test value for four separate mixes.

Table 4.1: Slump test results.

MIRHA (%)	Code	Average Slump Value (mm)
0	A1, B1 and C1	230
3	A2, B2 and C2	210
5	A3, B3 and C3	220
7	A4, B4 and C4	200

The slump pattern may take one of three forms; true slump, shear slump and collapse slump. In a true slump the concrete simply subsides, keeping more or less to the original cone shape. Whereas in shear slump, the top portion of the concrete shears off and slips sideways. On the other hand, in collapse slump, the concrete collapses completely at slump height more than 160mm. Based on the results obtained, the slump was categorized as collapse slump. Since it was collapse slump, the test was repeated several times to attain accurate value. Hence, average slump value was recorded accordingly.

4.2 POLYMERIC CONCRETE INTEGRITY

Ultrasonic Pulse Velocity (UPV) test was done to further analyze the degree of homogeneity of polymeric concrete produced. Table 4.2 illustrates the results of Ultrasonic Pulse Velocity (UPV) test conducted according to different MIRHA percentage added to the polymeric concrete. Whereas, Figure 4.1, Figure 4.2 and

Figure 4.3 show the graph variation of the Ultrasonic Pulse Velocity (UPV) test taken from the analysis at different curing method.

Table 4.2: Ultrasonic Pulse Velocity (UPV) results.

Code	3 days (km/s)	7 days (km/s)	28 days (km/s)
A1-0%	3.64	2.63	3.08
A2-3%	3.92	3.13	3.15
A3-5%	3.45	2.99	3.33
A4-7%	3.64	3.03	3.15
B1-0%	2.70	2.82	3.05
B2-3%	3.28	3.23	3.37
B3-5%	3.08	3.23	2.83
B4-7%	2.99	3.23	3.11
C1-0%	3.48	3.68	4.05
C2-3%	3.36	3.42	3.85
C3-5%	3.03	3.42	3.75
C4-7%	3.17	3.45	3.85

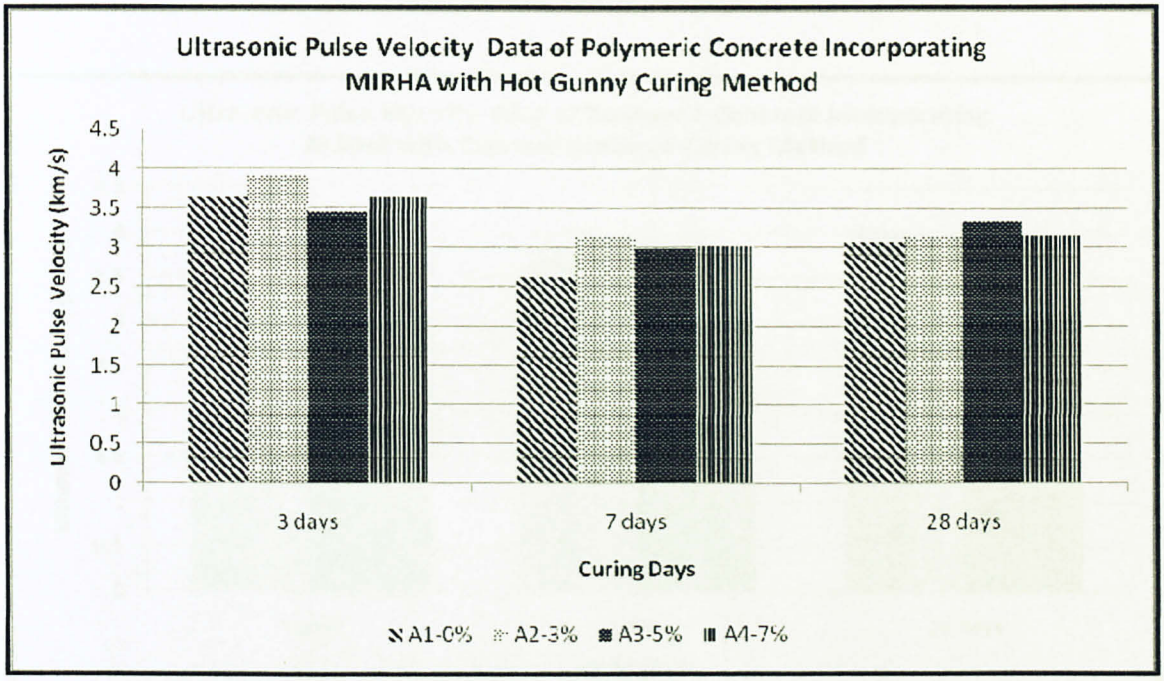


Figure 4.1: Graph of Ultrasonic Pulse Velocity (UPV) test results for hot gunny curing method.

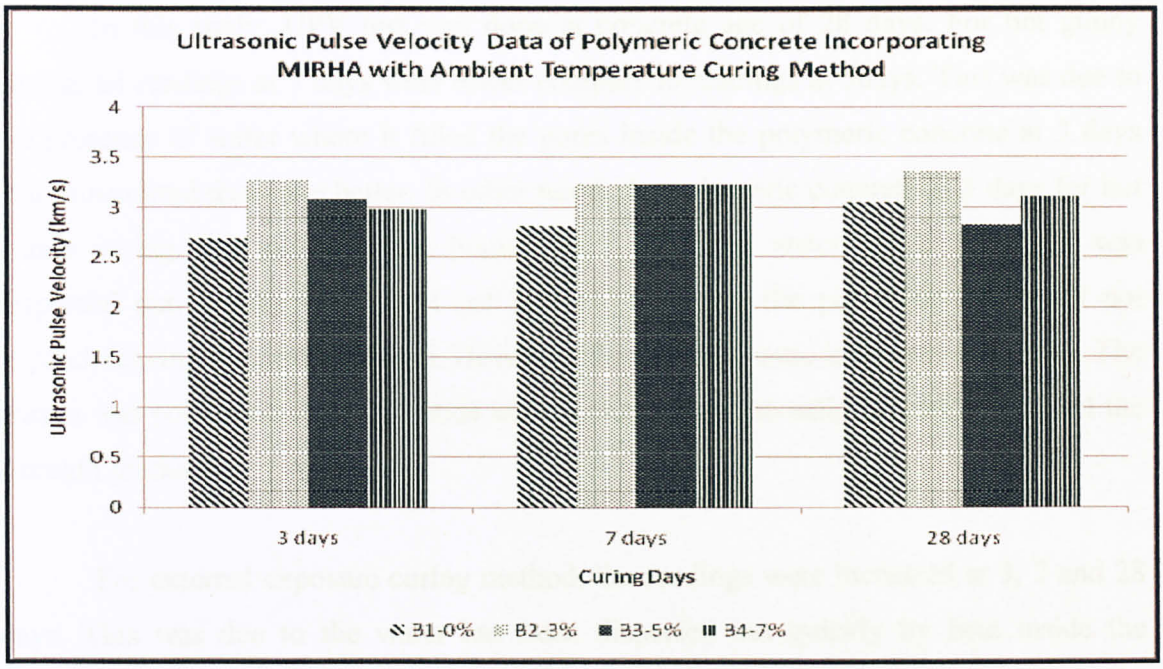


Figure 4.2: Graph of Ultrasonic Pulse Velocity (UPV) test results for ambient temperature curing method.

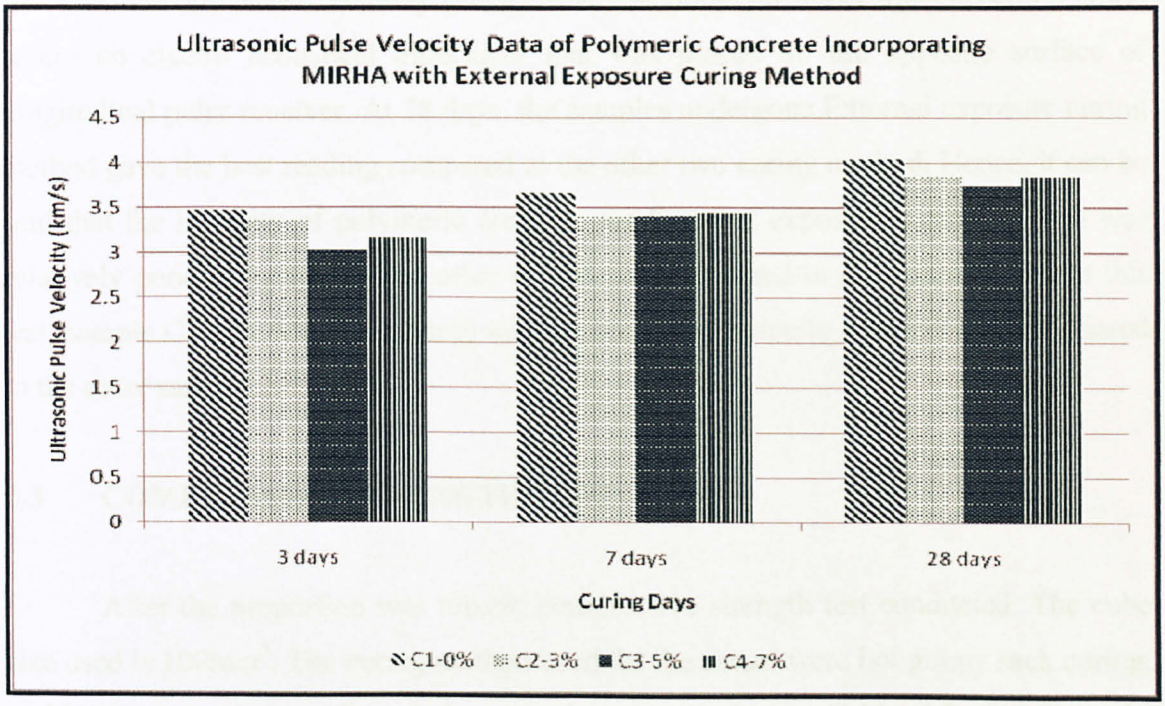


Figure 4.3: Graph of Ultrasonic Pulse Velocity (UPV) test results for External exposure curing method.

In this study, UPV test was done at concrete age of 28 days. For hot gunny curing, all readings at 7 days were lower compare to readings at 3days. This was due to the presence of water where it filled the pores inside the polymeric concrete at 3 days that transmitted the wave better. In other word, the polymeric concrete at 3 days for hot gunny curing was still wet and humid. In 7 days, the water inside the pores was dispersed out. Unlike the C-S-H gel in OPC concrete, the polymeric paste did not expand, leaving the pores unfilled. However, the readings were increased at 28days. The reason was polymeric reaction inside the concrete started to stabilize and developed the strength gradually.

For external exposure curing method, the readings were increased at 3, 7 and 28 days. This was due to the water has been dispersed out quickly by heat inside the chamber. The polymeric reaction started to stabilize faster compared to the sample in the other two curing methods with assistance of high temperature in the chamber at 7 and 28 days. Hence, the readings were consistently increased from 3, 7 and 28 days of testing.

Ultrasonic Pulse Velocity (UPV) Test was done via direct transmission method where an electro acoustical transducer that was placed on the opposite surface of longitudinal pulse receiver. At 28 days, the samples undergone External exposure curing method gave the best reading compared to the other two curing method. Hence, it can be said that the integrity of polymeric concrete for External exposure curing method was relatively good compared to the other two methods adopted in this research. From this test, sample C1 (0% MIRHA added) was the best pulse velocity measurement compared to the other samples.

4.3 COMPRESSIVE STRENGTH TEST

After the proportion was mixed, compressive strength test conducted. The cube size used is 100mm^3. The curing method used for the actual were hot gunny sack curing, ambient temperature curing, and external exposure curing Table 4.3 describes the compressive strength results for the actual mix of polymeric concrete. Figure 4.4,

Figure 4.5 and Figure 4.6 show the graph variation of the compressive strength test obtained from the analysis at different curing method.

Table 4.3: Compressive strength test results of the actual mix.

Mix Code	Curing Method	3 days (MPa)	7 days (MPa)	28 days (MPa)	56 days (MPa)
A1-0%	**Hot Gunny**	4.67	10.53	15.50	16.62
A2-3%		3.43	8.41	12.83	14.96
A3-5%		5.33	11.31	19.01	22.66
A4-7%		3.19	7.01	11.50	12.77
B1-0%	**Ambient Temperature**	7.46	14.11	19.73	21.92
B2-3%		6.30	11.05	17.92	19.19
B3-5%		9.38	14.74	25.30	27.28
B4-7%		8.55	11.35	16.75	17.03
C1-0%	**External Exposure**	32.78	44.76	48.88	50.96
C2-3%		19.93	24.96	35.20	36.35
C3-5%		14.14	24.29	28.70	33.62
C4-7%		16.81	30.22	41.34	44.84

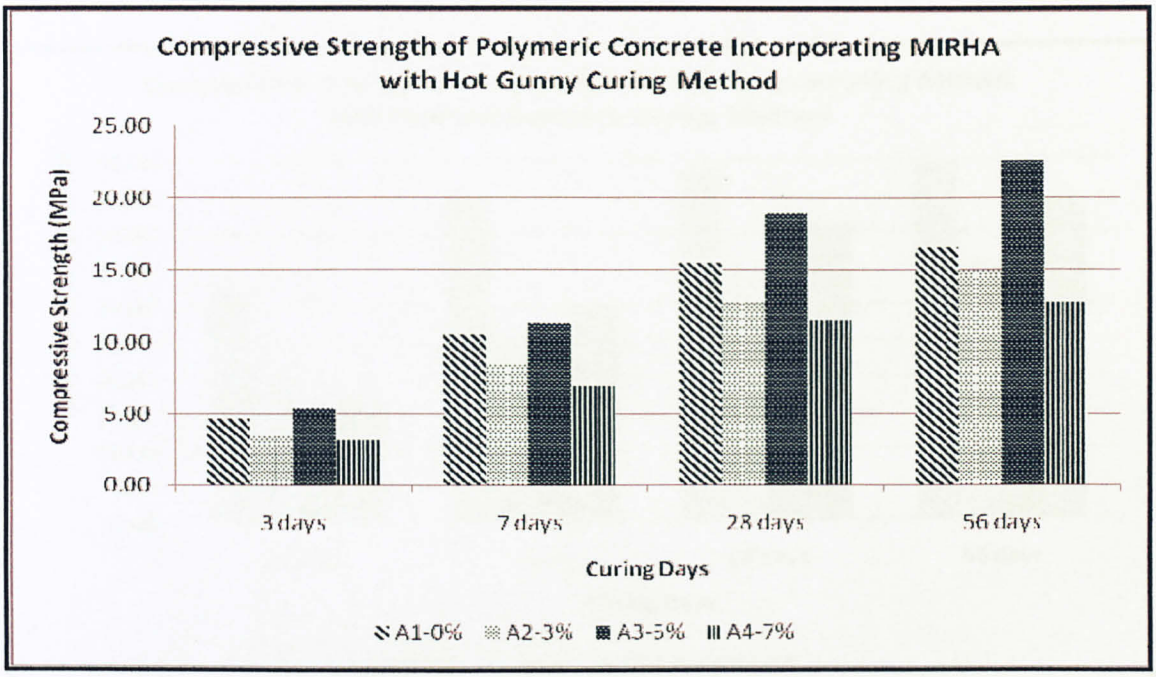


Figure 4.4: Graph of compressive strength test results for hot gunny curing method.

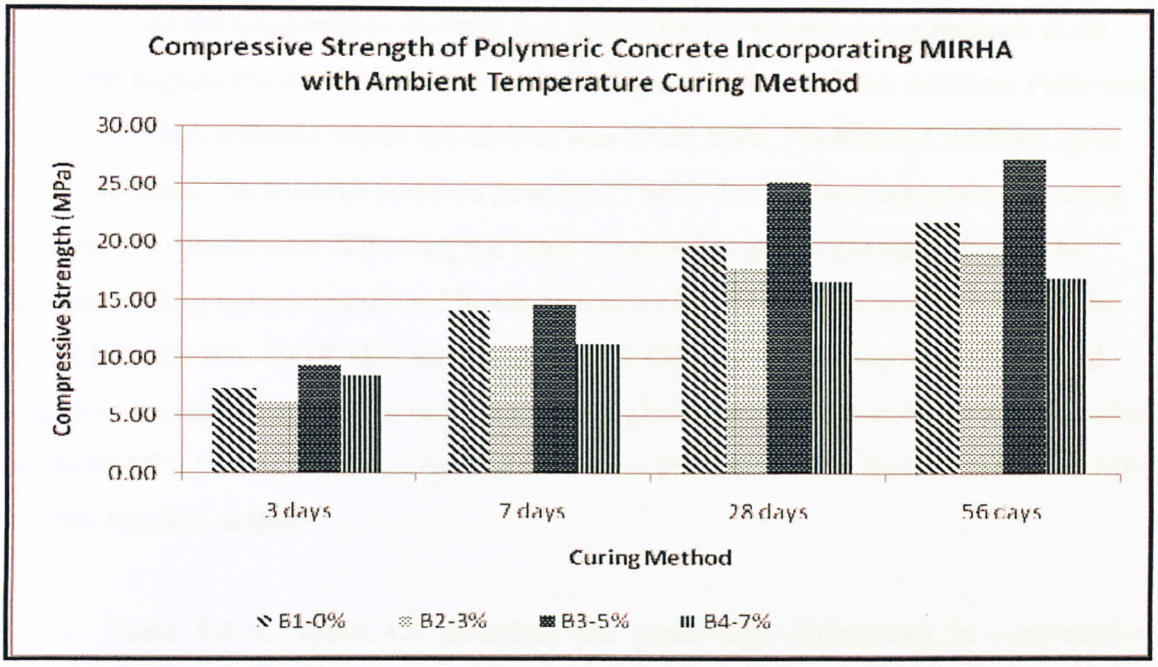


Figure 4.5: Graph of compressive strength test results for ambient temperature curing method.

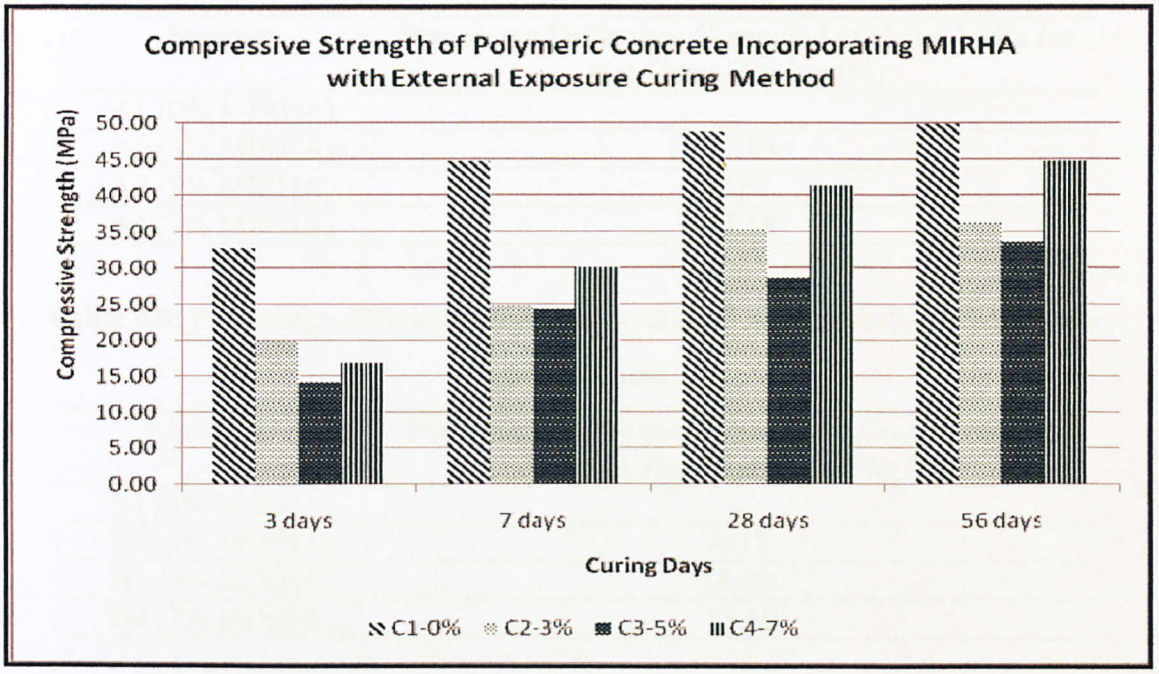


Figure 4.6: Graph of compressive strength test results for External exposure curing method.

From the compression strength test results for hot gunny curing method, at 56 days, the highest result was recorded as 22.66 MPa with 5% MIRHA addition. Followed by 0% MIRHA addition where the reading was 27.28 MPa, 3% MIRHA addition gave 14.96 MPa and 7% MIRHA addition gave 12.77 MPa. For ambient temperature curing method, the results were following the same trend as hot gunny curing method. The highest reading was recorded for 5% which was 27.28 MPa. These results followed by 21.92 MPa for 0%, 19.19 MPa for 3% and 17.03 MPa for 7%. However, for External exposure curing, the trend was not same. The highest compressive strength was recorded as 50.96 MPa for 0%, followed by 44.84 MPa for 7%, 36.35 MPa for 3% and 33.62 MPa for 5% MIRHA added.

Table 4.4 to Table 4.6 describes the percentage differences in compressive strength for all curing regimes compared to control mix which was 0% MIRHA addition at 28 days.

Table 4.4: Percentage difference compared to control mix for hot gunny curing method.

Samples	Percentage Difference Compared to Control Mix for Hot Gunny Curing (%)
A1 (0% MIRHA)	-
A2 (3% MIRHA)	-17.23
A3 (5% MIRHA)	22.65
A4 (7% MIRHA)	-25.58

Table 4.5: Percentage difference compared to control mix for ambient temperature curing method.

Samples	Percentage Difference Compare to Control Mix for Ambient Temperature Curing (%)
B1 (0% MIRHA)	-
B2 (3% MIRHA)	-9.17
B3 (5% MIRHA)	18.09
B4 (7% MIRHA)	-15.10

Table 4.6: Percentage difference compared to control mix for external exposure curing method.

Samples	Percentage Difference Compare to Control Mix for External Exposure Curing (%)
C1 (0% MIRHA)	-
C2 (3% MIRHA)	-27.99
C3 (5% MIRHA)	-41.28
C4 (7% MIRHA)	-15.43

In hot gunny, only A3 sample had higher compressive strength compared to other samples. On the other hand, sample B3 in ambient temperature followed the same trend, where the compressive strength of polymeric concrete was optimum at 5% of MIRHA addition. However, the trend changed in external exposure. C1, which was the control sample, was recorded to have higher compressive strength compared to the other sample in the said curing regime.

Reasons for the performance variation of polymeric concrete are many. For external exposure curing method, the main reason that the best result achieved was not at 5% MIRHA addition can be due to inconsistency of chamber temperature as the sample in chamber already increasing in number. Thus the temperature can be highly reduced that affects the polymerization process of polymeric concrete in the chamber. Moreover, the control sample, indicated as C1 with 0% MIRHA addition was placed first in the chamber. Hence, it produced high compressive strength compared to other samples since it undergone polymerization process effectively.

Curing is one of the vital parts in concrete hardening process. In order to achieve good compressive strength development of the concrete, proper curing must be done. In polymeric concrete, surrounding heat assisted in strength development. Longer curing time improved the polymerization process. The strength development is rapid up to 24 hours of curing time.

4.4 SCANNING ELECTRON MICROSCOPY ANALYSIS (SEM)

Scanning Electron Microscopy (SEM) analysis was done at concrete age of 28days to describe the microstructure condition of the produced polymeric concrete at various percentage of MIRHA replacement.

4.4.1 Hot Gunny Curing Method

For hot gunny curing method, the SEM images were taken at 10μm and magnified at 1000 times. Figure 4.7 to Figure 4.10 illustrated the results obtained in SEM analysis.

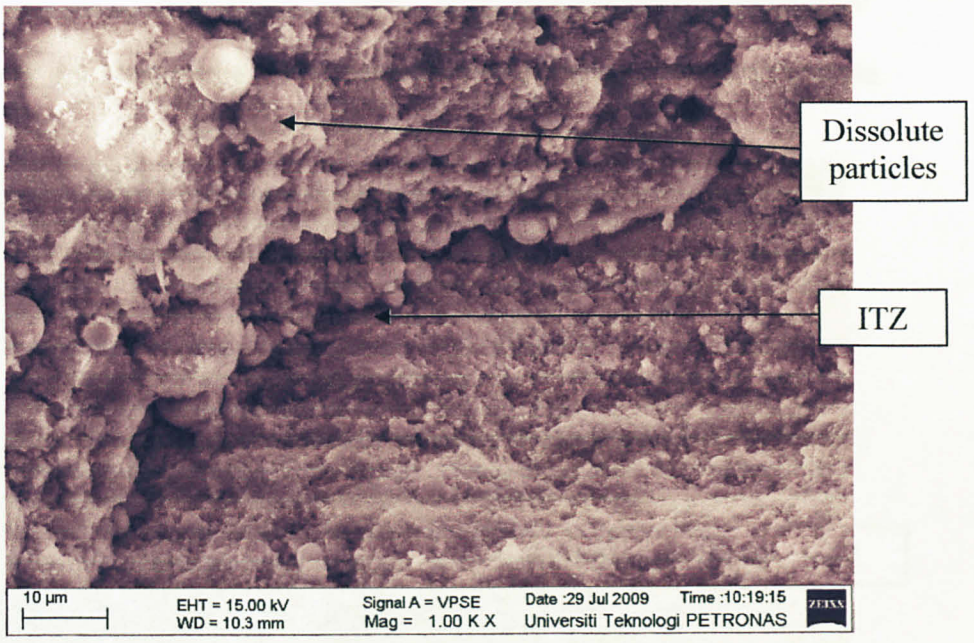


Figure 4.7: Scanning Electron Microscopy (SEM) figure for A1 sample.

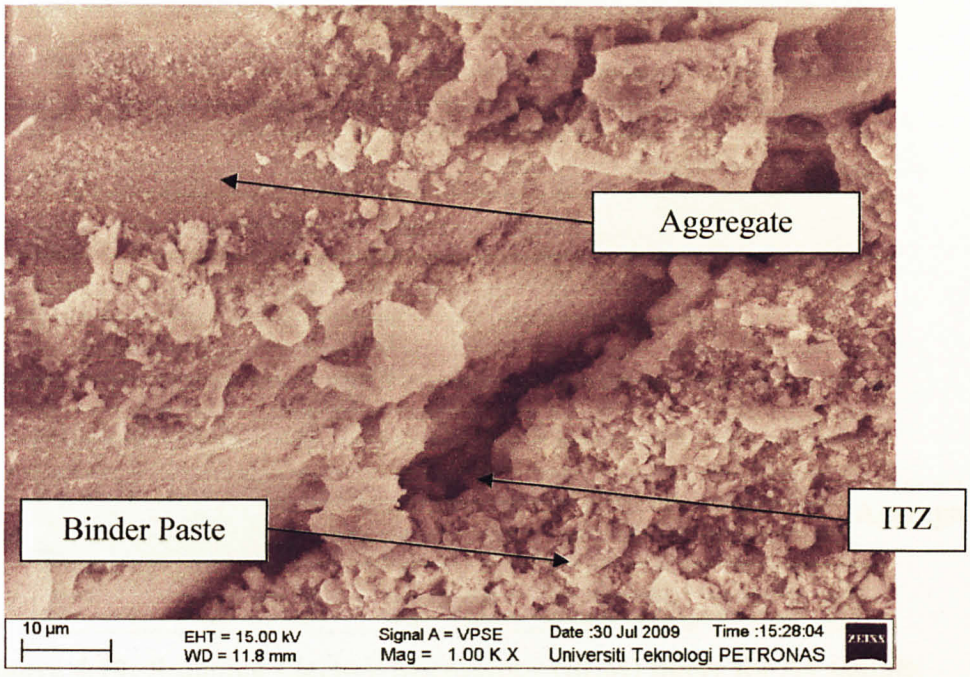


Figure 4.8: Scanning Electron Microscopy (SEM) figure for A2 sample.

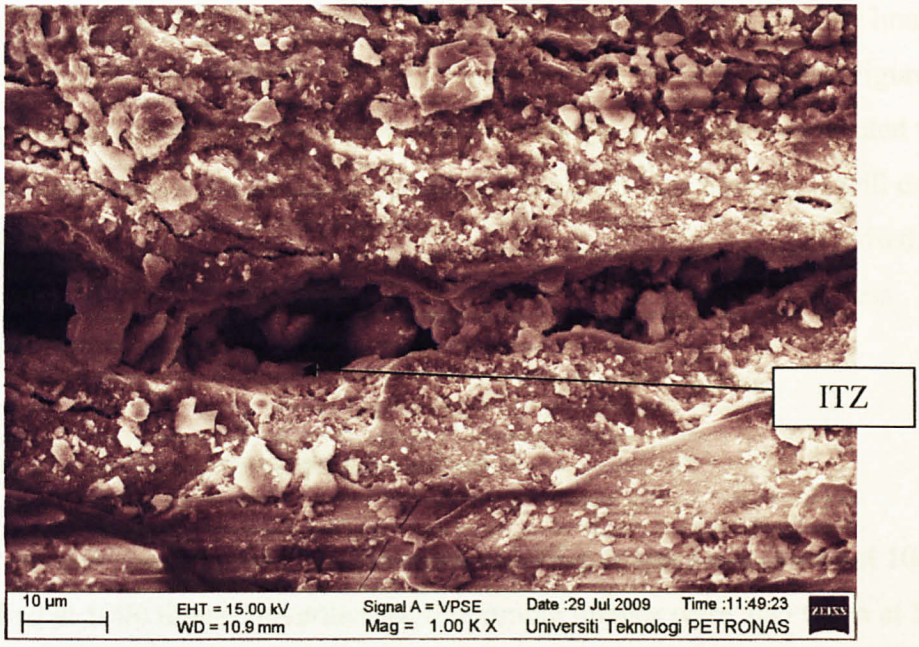


Figure 4.9: Scanning Electron Microscopy (SEM) figure for A3 sample.

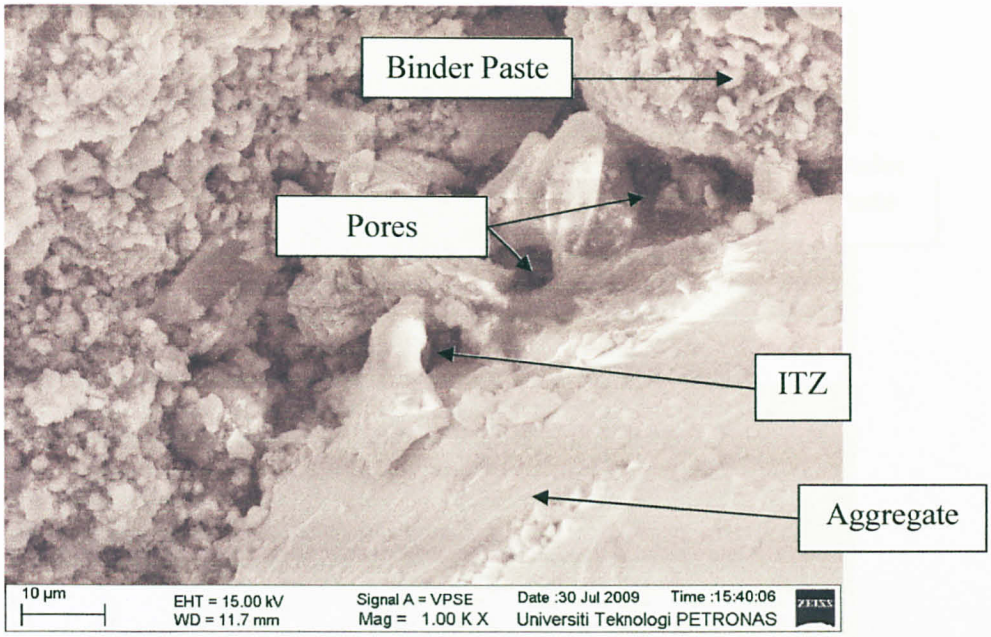


Figure 4.10: Scanning Electron Microscopy (SEM) figure for A4 sample.

From the images obtained, the binder paste, sodium aluminosilicate gel were not fully developed in all samples. The weakest point, ITZ was identified in every image where it led to microcrack. Dissolute particle can be seen in A1 sample (See Figure 4.7) which indicates that the silica and alumina from the binder, PFA were not reacted with the alkali activator. When the binder was dissolute in polymeric concrete, it will cause pores in the concrete produced. In Figure 4.10, existences of pores were identified. Pores in concrete indicate that the polymeric concrete was not fully integrated and less homogenous.

4.4.2 Ambient Temperature Curing Method

For ambient temperature curing method, the SEM images were taken at 10µm and magnified at 1000 times. Nevertheless, the sample images were also taken at 1µm and magnified at 5000 times to illustrate the binder paste, sodium aluminosilicate gel formation. Figure 4.11 to Figure 4.15 illustrated the results obtained in SEM analysis.

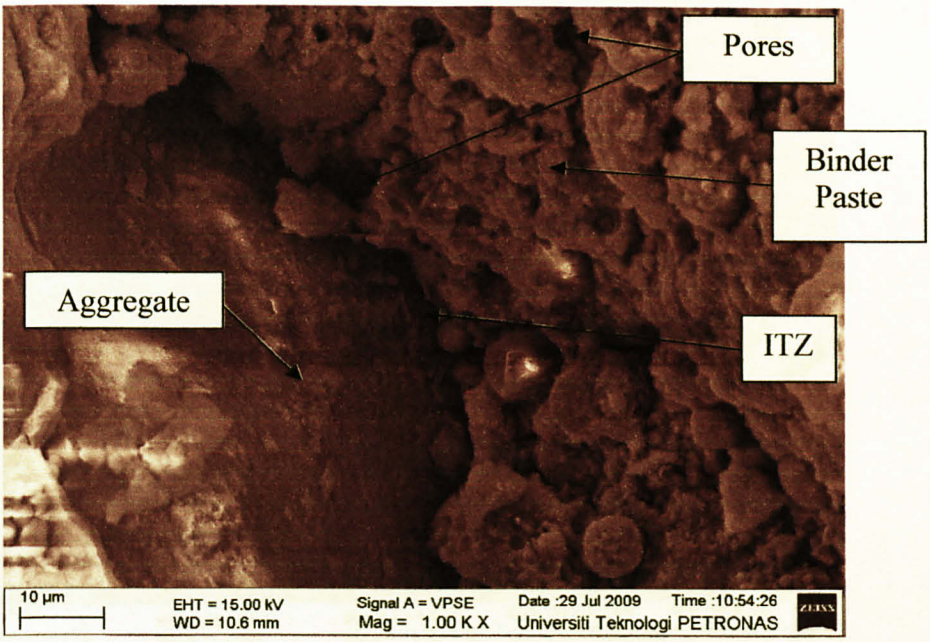


Figure 4.11: Scanning Electron Microscopy (SEM) figure for B1 sample at 1000 times magnifying.

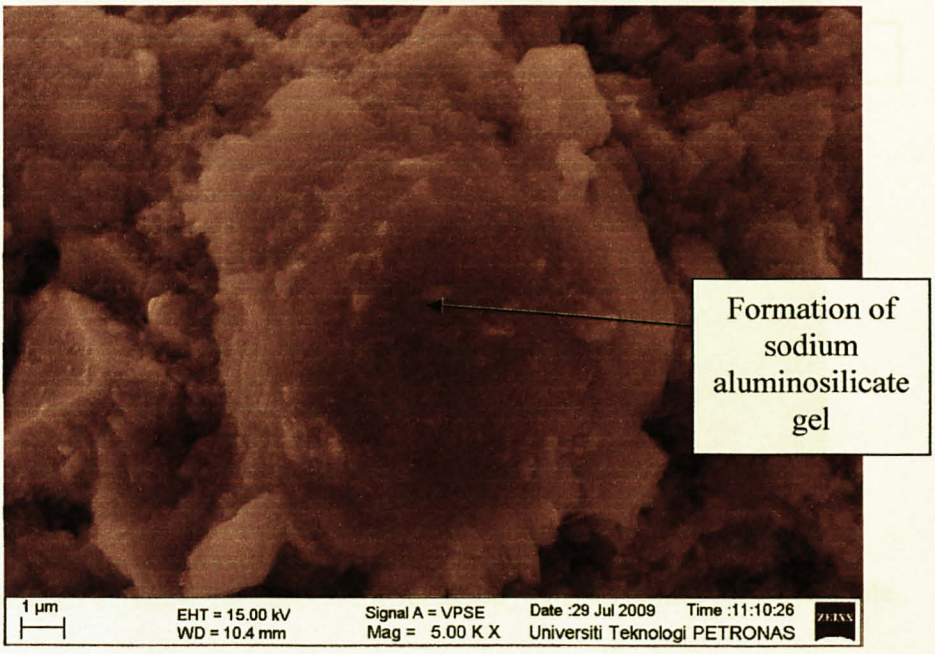


Figure 4.12: Scanning Electron Microscopy (SEM) figure for B1 sample at 5000 times magnifying.

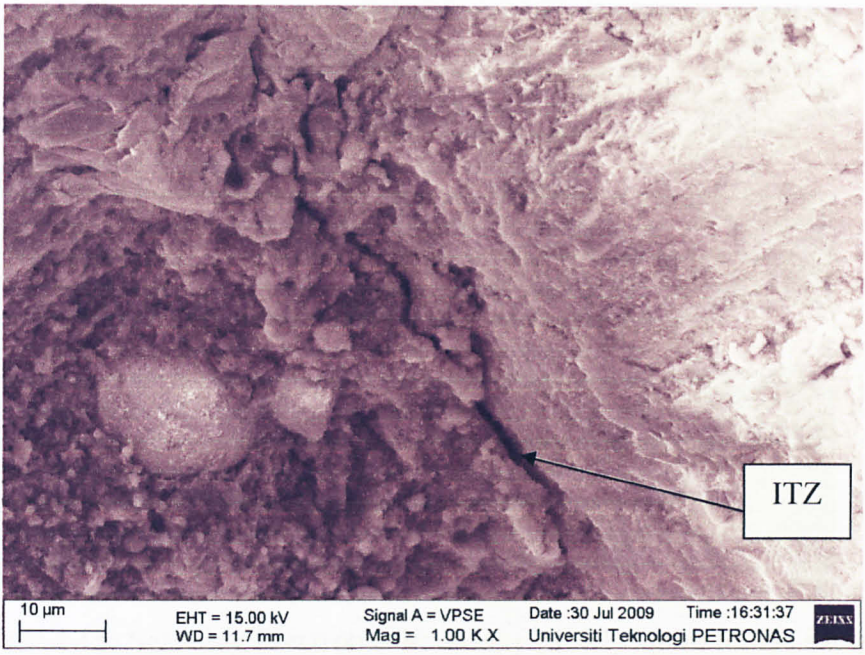


Figure 4.13: Scanning Electron Microscopy (SEM) figure for B2 sample.

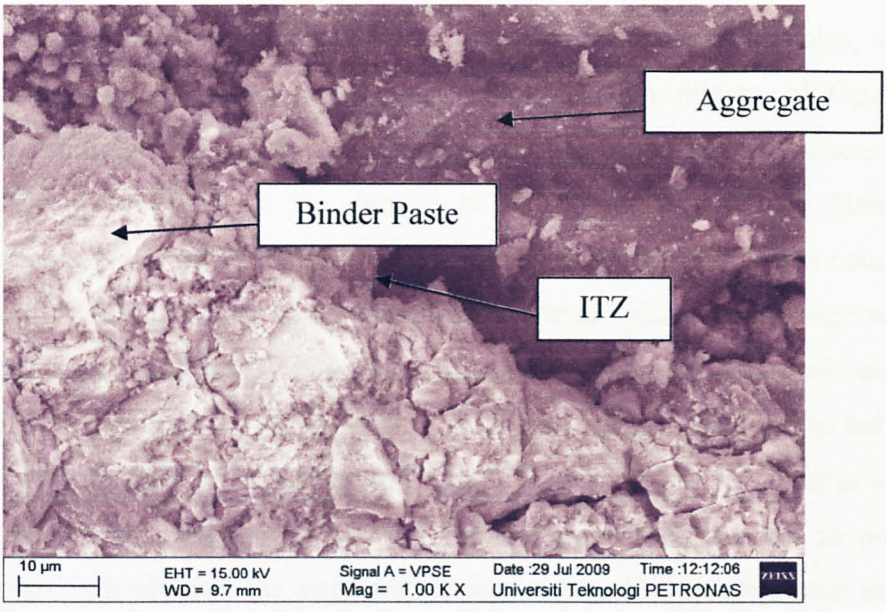


Figure 4.14: Scanning Electron Microscopy (SEM) figure for B3 sample.

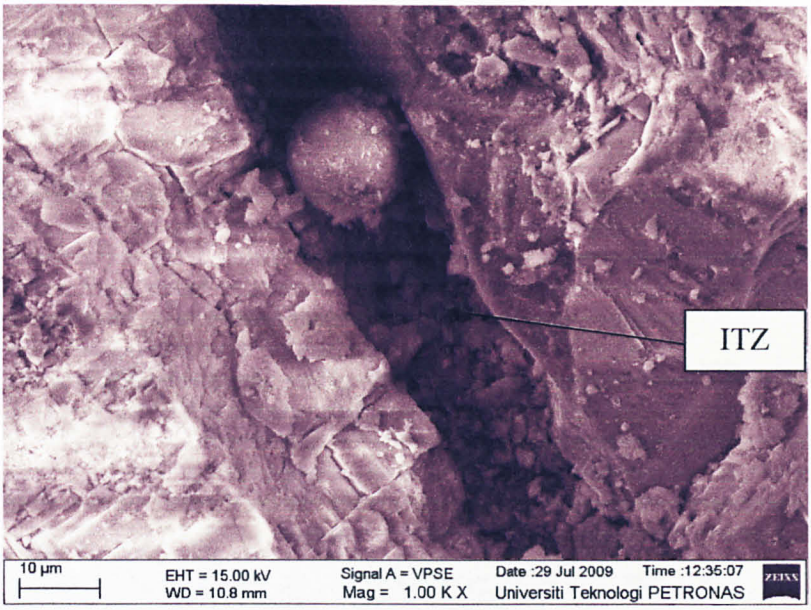


Figure 4.15: Scanning Electron Microscopy (SEM) figure for B4 sample.

From the images obtained, the binder paste, sodium aluminosilicate gel were also not fully developed in all samples. However, compared to hot gunny samples, ambient temperature samples produced higher amount of sodium aluminosilicate gel. Figure 4.12 illustrates the formation of sodium aluminosilicate gel in polymeric concrete. The developed binder paste increased the strength of the polymeric concrete. Hence, the compressive strength of ambient temperature samples was noted to be higher compare to hot gunny samples. On the other hand, the ITZ was identified in every image where it led to microcrack and thus affected the strength of the generated polymeric concrete. However, the ITZ in ambient temperature were having lesser gap compared to hot gunny samples. Moreover, pores were identified in Figure 4.11. The existence of pores was due to the polycondensation reaction to develop sodium aluminosilicate gel in progress. Pores in concrete indicate that the polymeric concrete was less homogenous and thus low compressive strength.

4.4.3 External Exposure Curing Method

For external exposure curing method, the SEM image were taken at 10μm and magnified at 1000 times. Figure 4.16 to Figure 4.19 illustrated the results obtained in SEM analysis.

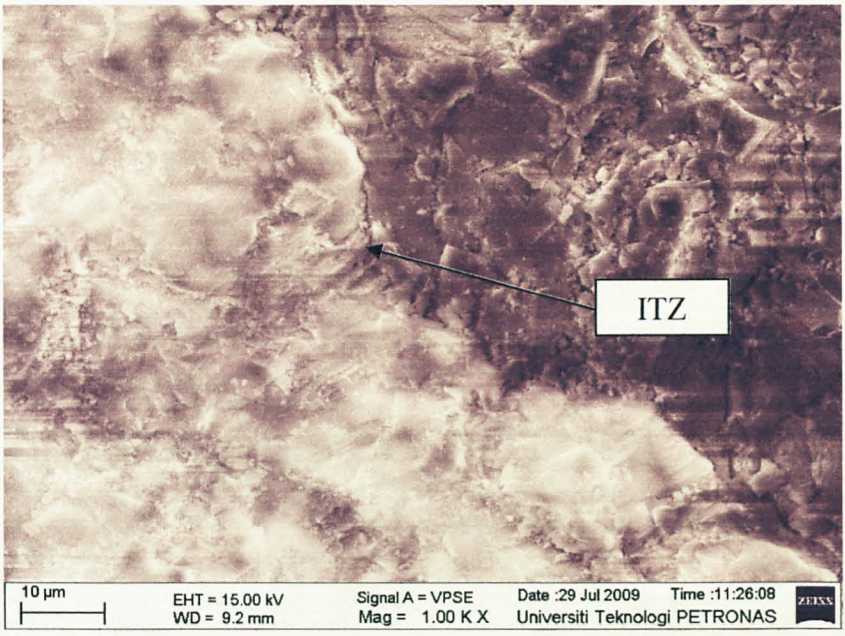


Figure 4.16: Scanning Electron Microscopy (SEM) figure for C1 sample.

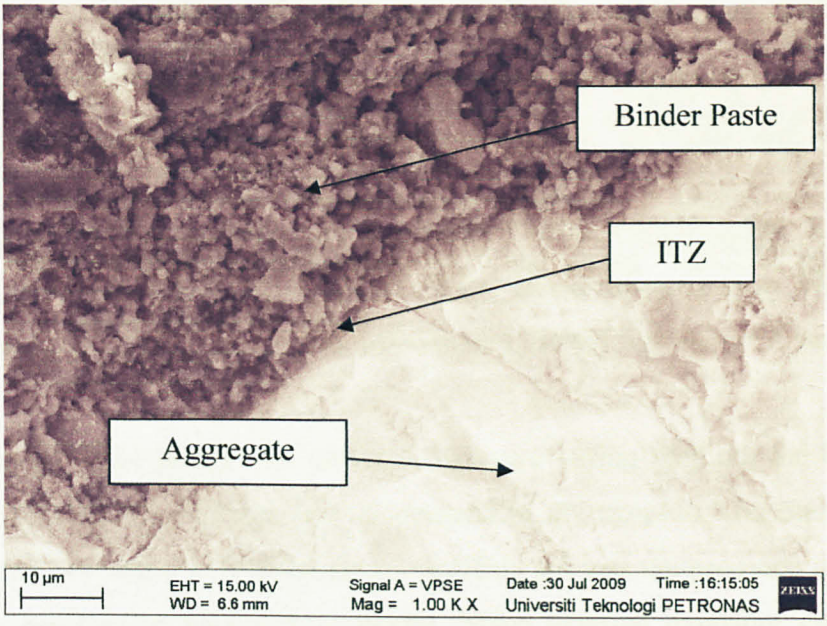


Figure 4.17: Scanning Electron Microscopy (SEM) figure for C2 sample.

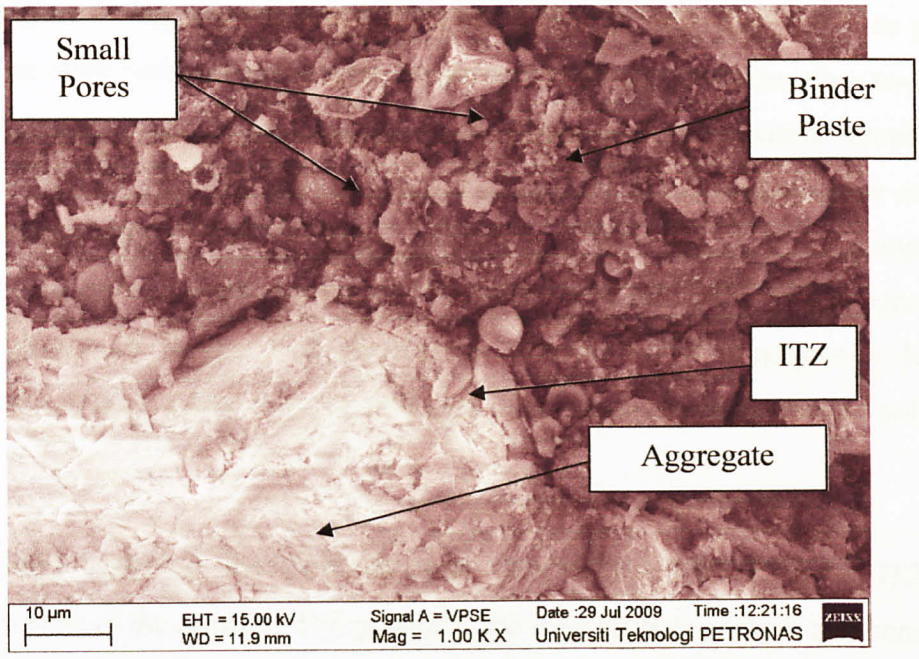


Figure 4.18: Scanning Electron Microscopy (SEM) figure for C3 sample.

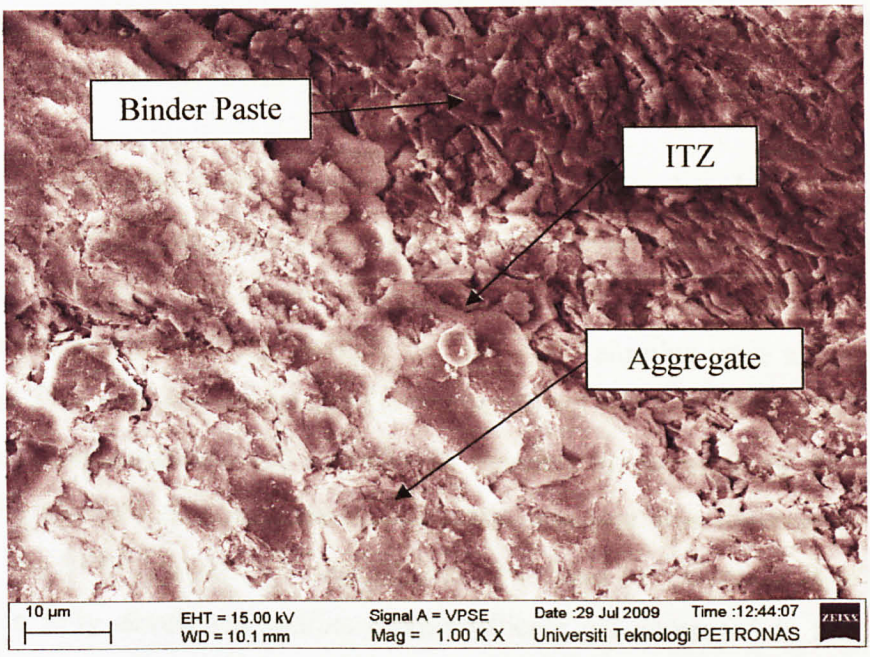


Figure 4.19: Scanning Electron Microscopy (SEM) figure for C4 sample.

From the SEM images for external exposure curing method, the binder paste, sodium aluminosilicate gel were fully developed in all samples. The main factor that contributed the formation of sodium aluminosilicate gel was the presence of heat due to endothermic reaction in polymeric concrete. Since external exposure curing method

provided higher curing temperature, the formation of sodium aluminosilicate gel was better among other curing regimes used in this study. Compared to the other two curing regimes, hot gunny and ambient temperature, the ITZ in external exposure samples were having smaller gap. This phenomenon indicated that the binder and alkaline activator were undergone well polycondensation reaction and thus having better compressive strength. Since the samples undergone the reaction well, only small pores were identified clearly in Figure 4.18. Hence, the integrity and homogeneity between aggregate and binder paste were at optimum level and achieved quality polymeric concrete.

Overall, based on the SEM analysis, interfacial transition zone (ITZ) was identified in most of the samples. ITZ generally the weakest link of chain and considered as the strength limiting phase in concrete. The microstructure of the ITZ has a great influence on the stiffness of the concrete. Hence the presence of ITZ basically showed the potential microcracks presence and it leads to failure of the concrete.

On the other hand, sodium aluminosilicate gel was developed in almost all of the samples. This indicated that polycondensation, which was the reaction of polymerization of polymeric concrete took place. Hence, the strength of the concrete was being developed accordingly. Dissolute particle i.e. silica and alumina were also captured in this analysis. This was due to the alkaline activator did not react with the particles to form sodium aluminosilicate gel in order to develop the strength of the polymeric concrete. The strength development of polymeric concrete was assisted by heat. By referring to the SEM analysis, C1 sample that was cured by external exposure curing method has a fully developed sodium aluminosilicate gel compared to other sample. Thus, the compressive strength of the said sample was higher compare to other sample.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Considering polymeric concrete as an alternative to Ordinary Portland cement, it is a positive stepping stone towards a greener concrete usage in construction world. Hence, utilizing PFA as the major constituent in polymeric concrete will reduce the abundance of by-product and waste material worldwide.

From the tests conducted, the compressive strength of polymeric concrete that undergone external exposure curing method was the best compared to other type of curing method. In the curing method, control sample, C1 (0% MIRHA added) achieved the highest compressive strength which was 48.88MPa at 56 days. Meanwhile, based on UPV test at 28 days, the high integrity of polymeric concrete can be observed at the sample of external exposure method where sample C1 (0% MIRHA added) was having the best pulse velocity reading, 4.05 km/s. According to Neville (1990), concrete that gained UPV measurement more than 4 km/s is considered as a good concrete. For rebound hammer test at 28 days, it also follow the same trend where the highest surface hardness measurement were the samples that undergone external exposure curing method. However, it was noted that the highest surface hardness reading taken was sample C3 (5% MIRHA added).

In SEM analysis, the ITZ can be seen in some of the samples where it lead to microcrack and affect the strength of the polymeric concrete produced. ITZ in external exposure was having small gap compared to other curing regimes. Hence, it shows that presence of heat in external curing method is vital in polymeric concrete strength development. Pores inside the concrete were also detected. Only small pores identified in external exposure curing. This is due to the samples in that curing regime undergone polycondensation reaction between alkali activator and binders well. On the other hand, dissolute particle and formation of sodium aluminosica gel were also observed. These facts indicate that the alkaline activator i.e. sodium hydroxide and sodium silicate was

not yet fully reacted with the binders namely silica and alumina to develop the polymeric strength.

Overall, based on the testing done in this project, the best curing method for polymeric concrete production is external exposure curing method. From all the test results, it is proven that presence of heat assisted the polymeric concrete strength development.

5.2 RECOMMENDATION

In this project, further test should be done to identify the capacity of polymeric concrete in depth. Production of polymeric concrete should be developed using different density of main binder namely PFA in future research. Apart from that, the effect of different additional water and sugar amount as retarder should be investigated thoroughly in order to ascertain clear relationship in polymeric concrete production.

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